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The first billion years

The Big Bang launched an era of brilliance that lasted nearly 400,000 years. But darkness then fell upon the cosmos, and didn't relinquish its grip for a billion years. p. 30

ASTRONOMICAL HISTORY

Stargazing in ancient Egypt p. 62

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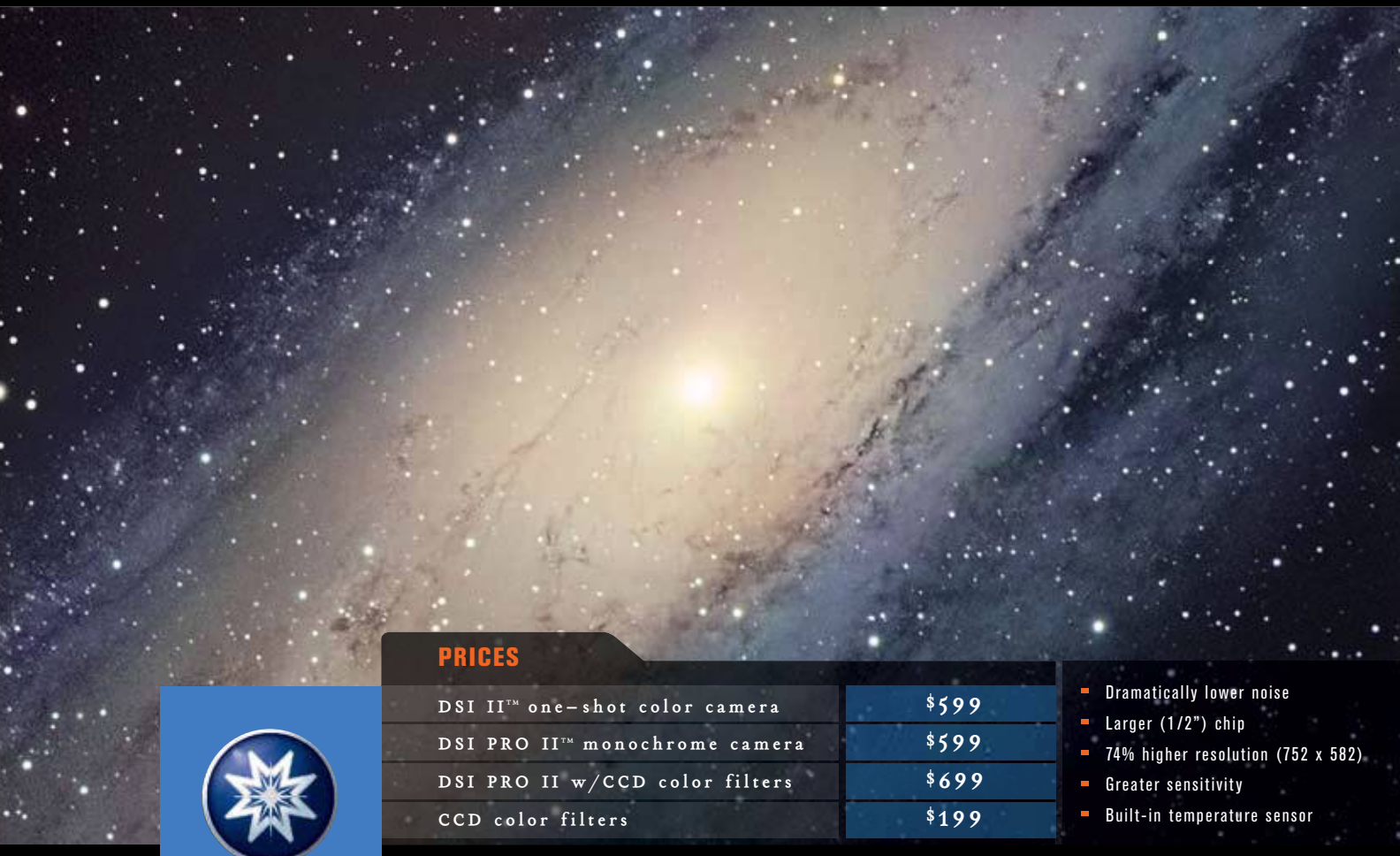
"The new DSI PRO II is definitely a contender with the big boys." - Steve Hamilton



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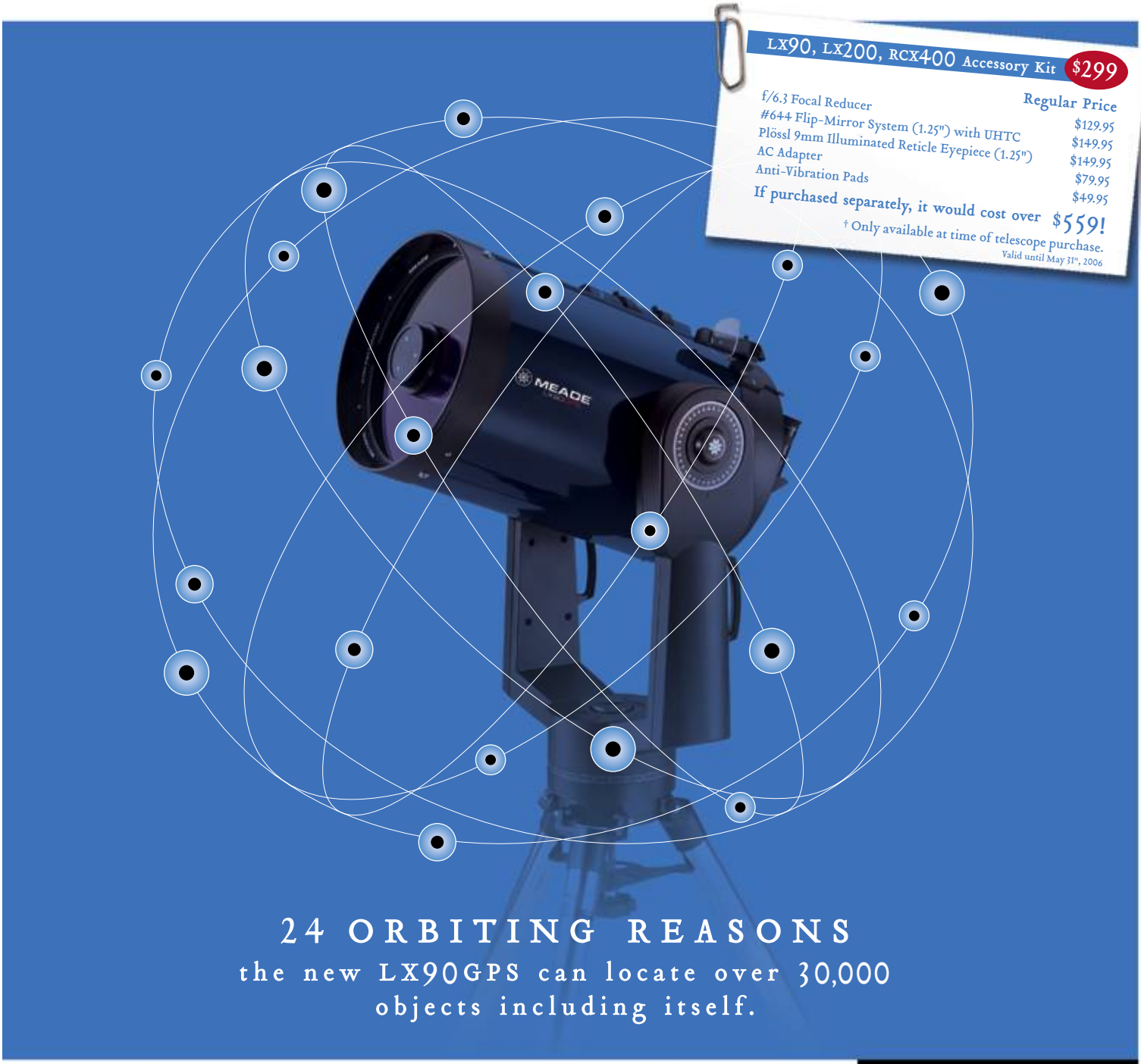

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ASTRONOMY: ROEN KELLY

ON THE COVER

The Big Bang created the universe and flooded it with light. But the brilliance was short-lived: Just 380,000 years later, darkness settled over the cosmos — and didn't relinquish its grip for a billion years. Astronomers are just starting to learn what these Dark Ages were like, and how Nature was able to re-light the universe.

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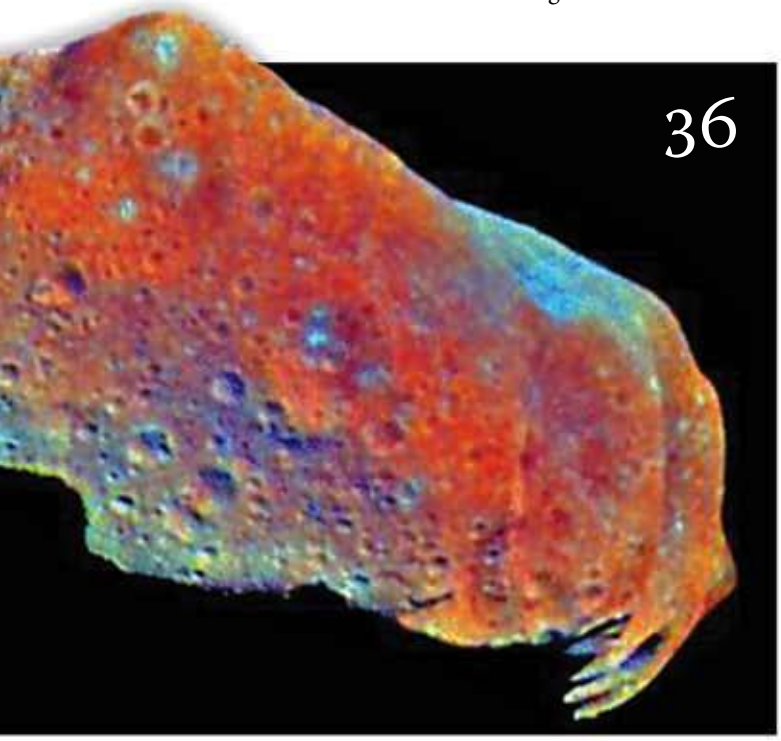
Observing, telescopes, origin and fate of the cosmos

VOL. 34, NO. 6

june 2006



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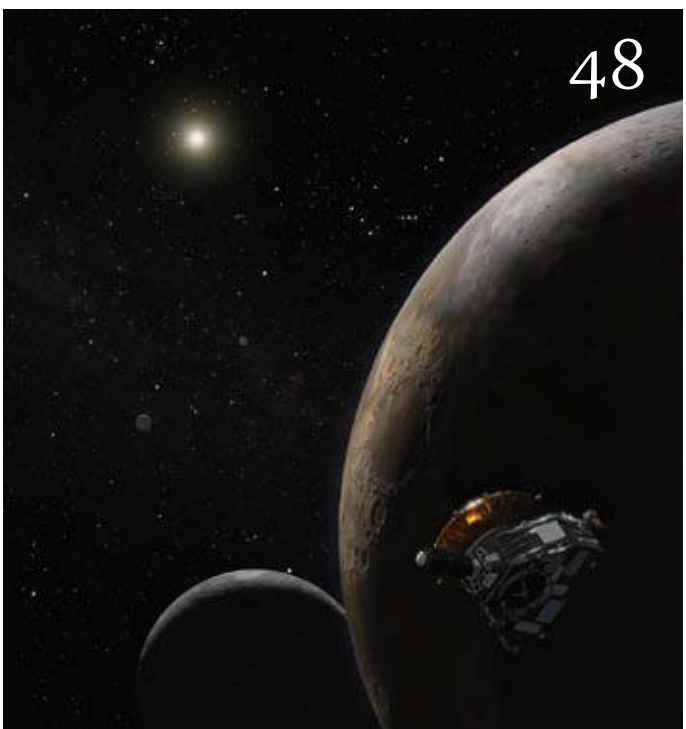

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STScI

The real Dark Ages

When someone mentions the phrase

"Dark Ages" to refer to the early Middle Ages, I have to smile. Yes, the period from about A.D. 476 to A.D. 1000 was gravely dull and intellectually idle. But it was hardly dark. You wanna know about the real Dark Ages? Read University of Rochester astrophysicist Adam Frank's story, "The first billion years" (page 30). Less than 1 million years after the Big Bang, darkness fell over the universe unremittingly.

SENIOR EDITOR MICHAEL E. BAKICH

ASTRONOMY: WILLIAM ZUBACK

For a billion years, the cosmos existed as a black nothingness devoid of structures like stars and galaxies. Only near the end of this unfathomably long interval did the first stars form, lighting the dark clouds and bringing visibility into the early cosmos. Astronomers are now beginning to understand what happened during this great gulf, and the findings make spectacular reading.

Light is sometimes the key to understanding, other times color is. In "Seeing red" (page 36), sibling astronomers Peter and Robert Jedicke describe how scientists use reflective colors to classify asteroids. The dizzying number of asteroids out there, and the complex way they evolve — through colliding and fragmenting over time — make it extremely difficult to trace their origins. But the Jedickes describe new techniques enabling astronomers to piece together the story of asteroid relationships and place these space rocks into families.

Whether it is a bona fide planet or merely a wandering Kuiper Belt asteroid, Pluto has struck the astronomy world with big news once again. In 2005, planetary scientists S. Alan Stern and Hal Weaver discovered two new moons of Pluto. After more observations were made, Stern and Weaver confirmed the discovery in February 2006. In "How we discovered Pluto's new worlds" (page 44), we present the exclusive story of Stern and Weaver's discovery in their own words. Coupled with this amazing story is another terrific piece, "Are Pluto and Earth two of a kind?" by journalist Ray Villard (page 48), who explores the similarities between these two "binary-planet" systems.

Closer to home, I'm happy to announce Michael Bakich has been promoted to senior editor. Michael joined *Astronomy* as associate editor in February 2003. Before arriving at *Astronomy*, he was a planetarium consultant, lecturer, and writer. Michael has written three books for Cambridge University Press — *The Cambridge Guide to the Constellations*, *The Cambridge Planetary Handbook*, and *The Cambridge Encyclopedia of Amateur Astronomy*.

In his spare time, Michael enjoys woodworking, science-fiction movies, and book collecting. This last passion has led him on a lengthy search for 19th-century, first-edition astronomy books. Currently, his collection numbers more than 400 19th-century first editions. Michael also enjoys observing celestial objects with a variety of telescopes. He lives in Milwaukee with his wife Holley, who is an artist and graphic designer. Congratulations, Michael!

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 34, Number 6

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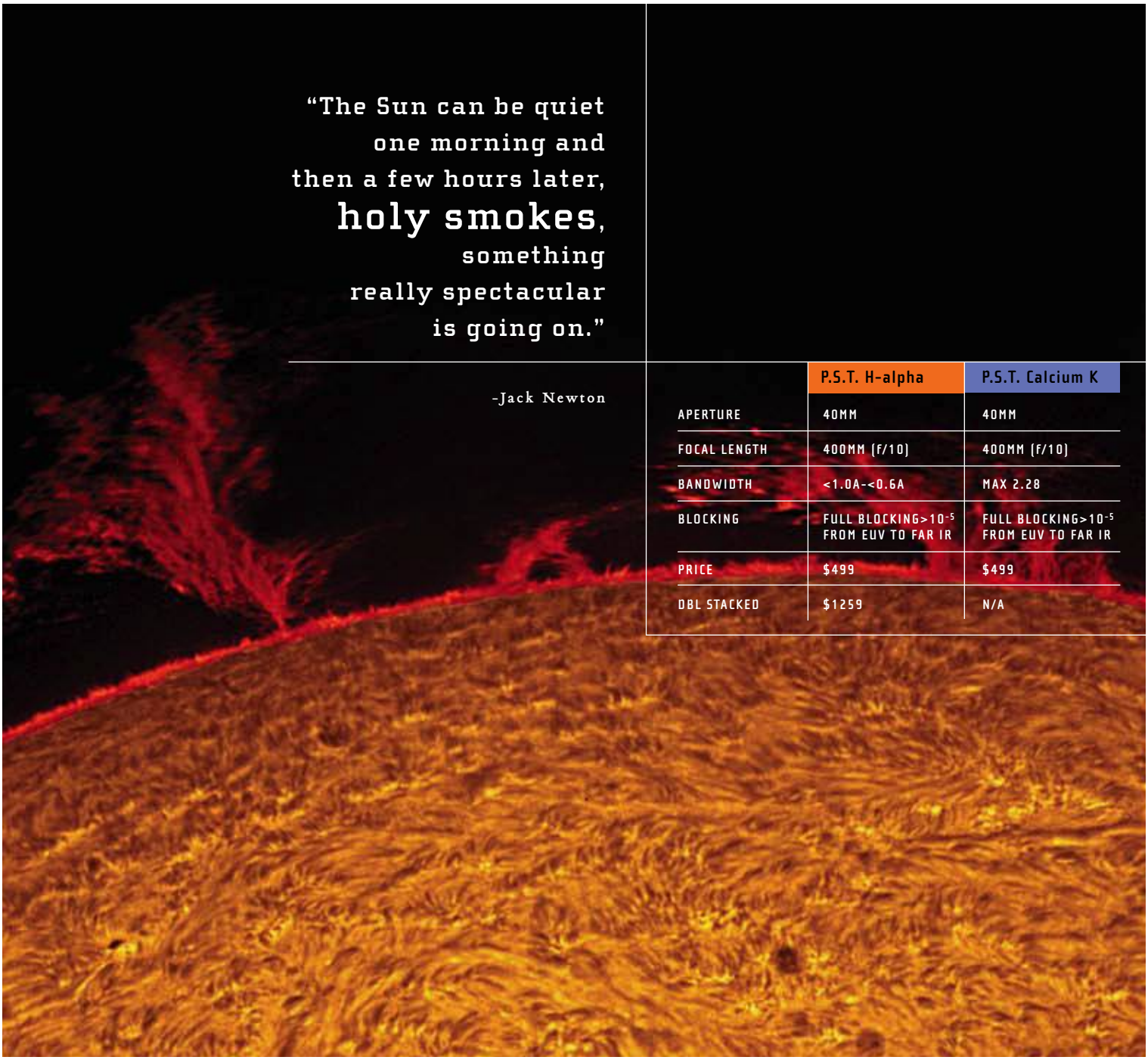

"The Sun can be quiet one morning and then a few hours later, **holy smokes**, something really spectacular is going on."

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NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

No DeLorean needed

February's "Is time on our side?" by Senior Editor Richard Talcott inspired great reader response. Here are some samples: ☾ I could hardly believe what I was reading. For an intelligent magazine like *Astronomy* to print an article that implies a man would travel to the past and kill his grandfather is simply appalling and atrocious. — **BILL SCAMPTON,** MYERSTOWN, PENNSYLVANIA

I took some comfort from the table on page 35, "Time travel into the future." Given all the airplane flights I've made during the last 45 years or so, I should be about 10,000 nanoseconds younger than ground-bound people. I do feel younger! — **LOREN BIRD,** MESA, ARIZONA

To travel back in time would be to bring the present with you, undoing all that had occurred, and leaving a blank canvas upon which to paint a new future. — **KEITH WICK,** GRAND RAPIDS, MINNESOTA

One problem with time travel into the past: There is no past. There is no universal record, movie, or interactive video game fixed in some other dimension that can be revisited, replayed, and relived. When scientists speculate about alternative universes containing our past, they enter another realm of science. It's called science fiction. — **GARY KERN,** GRAND TERRACE, CALIFORNIA

Maybe a simple proportion explains why we haven't seen time travelers. Place the number of universes in which we exist (1) over the number of universes that can visit us (infinite). Calculus lets us take the limit of 1/x as x approaches infinity. The answer is 0. Thus, the probability of us seeing a time traveler is 0. — **DAVID BARRY,** VIA E-MAIL

THE DAYS OF OUR LIVES tick by unrelentingly. Yet many physicists think the day will come when we can travel into the future — and maybe even the past.
ASTRONOMY: ROEN KELLY

Helpful captions appreciated

Most of the astronomical magazines I read show pictures of beautiful objects but make little attempt to explain them. As a first-time *Astronomy* reader, I commend your use of informative captions for images in Reader Gallery. — **BRYNNA C. BARTLETT,** HAMILTON, OHIO

Clyde Tombaugh's legacy

The article "More than a one-hit wonder" (February 2006) said Clyde Tombaugh searched for Pluto at Lowell Observatory for 14 years. The year of discovery, 1930, minus this time period implies Tombaugh arrived at Lowell well before when is stated in the article. Perhaps 14 months is more accurate? — **DENNIS BLANCHARD,** SAN JOSE, CALIFORNIA

A few other readers wrote in with a similar question. Actually, Tombaugh did *spend 14 years viewing the plates, beginning at the age of 23. He found Pluto early on in his project, but he continued to take photographic plates and study other astronomical objects. In fact, during those 14 years, he made a number of discoveries — variable stars and asteroids, for example — in addition to his observations of galaxy clustering.* — **LIZ KRUESI,** ASSISTANT EDITOR

My first encounter with Professor Tombaugh was a pleasant surprise. My train from Albuquerque had just pulled into the small station at Las Cruces, New Mexico. I strained to recognize my friend and mentor Walter Haas. A voice called out, "Are you Mr. Cross? I'm Clyde Tombaugh. Walter Haas couldn't make it. He sent me instead. I hope you're not disappointed." — **GENE CROSS,** FREMONT, CALIFORNIA

Correction

A caption on page 80 of the March issue states Equatorial Platforms doesn't build telescopes. The company builds SpicaEyes, a line of large-aperture reflectors with go-to drives. — ***ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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BY BOB BERMAN

Terms of endearment

Every hobby and profession has its own language, and astronomy is no exception. Some astronomical terms — horizon, for example — are known by almost everyone. Others — Hydrogen-alpha, for instance — are familiar mostly to professionals and serious amateurs.

Some terms are pure fun. They're fun either because they sound intriguing or they denote a little-known phenomenon that deserves wider recognition. Some terms merely sound cool.

Like **exeligmos**. Throw that one around at your next star party and see if anyone has a clue. It's a period of time: 54 years and 1 month. To get the same type of eclipse in your neighborhood again, you must wait 1 exeligmos. An exeligmos equals 3 saroses. Each **saros** lasts 18 years and 10⅓ (sometimes 11⅓) days. That's the common time span for a trio of lunar periods that makes an eclipse repeat itself. But that "⅓ day" places the next eclipse 120° of longitude west of the previous one.

The fabulous 6½-minute North American total solar eclipse of July 11, 1991, gets a reprise in the United States August 12, 2045, an exeligmos later. It'll be the longest totality in U.S. history.

How about **syzygy**? It's a good Scrabble word, except you need a blank. That's simply the three-way line-up of Earth, Moon, and Sun — like at Full Moon.

Parhelion is the name for a bright, colorful spot 22° to the left or right of the Sun. Its popular name is just as attractive: Sun Dog. How can anyone not like that?

Parhelion sounds like **perihelion**: the closest point to the Sun in our orbit, reached each year the first week of January.

I like **quadrature**, too, even though it's of trivial consequence: the position of a superior planet when 90° from the Sun in our sky. This month, Uranus is at quadrature, so it will hover on the meridian at sunrise. I like the word simply because it contains "rat."

How about **terminator**? It sounds cold and icy, thanks to the movies, but that day-night line — which on the Moon creeps along the surface at 10 mph (16 km/h) to deliver exquisite high-relief shadowing — makes the terminator the place to be when hauling out any backyard scope.

Event horizon is an appealing phrase; we need more like these. Its synonym, **Schwarzschild radius**, is not terrible either.

"Crepuscular" sounds so lovely. I use the word as much as possible.

The meaning is wild: the distance from a black hole's singularity, where light cannot escape because space-time is infinitely curved. It doesn't get much better than that.

Twilight wedge deserves to be here, too. That's the gray-blue horizontal band hugging the eastern horizon each evening at sunset. It's nothing less than Earth's shadow thrown into space. It's striking and obvious, so why isn't everyone aware of it?

While we're out at dusk, check out **crepuscular rays**. They're not visible every clear evening like the twilight wedge, but they're not rare. The dramatic fairyland rays, emanating from just below the horizon where the Sun lurks soon after sunset, come from light shafts poking over cloud tops beyond the horizon. Crepuscular means "pertaining to twilight." It sounds so lovely. I use the word as much as possible, even when it's not appropriate.

Lagrangian point. Does that have zing, or what? 'Twas named for Joseph Louis LaGrange (1736–1813), who identified five places where small objects can have happy, stable positions in equilibrium with the Earth's and Sun's gravities.

Know about **Trojan asteroids**? They're two bunches of big rocks in Jupiter's orbit circling the Sun while clustered 60° ahead of and behind the giant planet. They occupy Lagrangian points 4 and 5.

Two-word terms that contain a color are so catchy, they often get repeated by the media. **Green flash**, **black hole**, **brown dwarf**, **red giant**, **blue shift**. These phrases may be too well-known to qualify for our list, but they're snappy all the same.

Cerenkov radiation. It's sometimes spelled Kerenkov, which offers a much-needed clue to pronunciation. That's the violet-color glow emitted when something breaks the light-speed barrier. How cool is that? Of course, nothing outruns light in a vacuum. But in denser media, like in a nebula or a nuclear reactor's water-filled tank, the violet glow means copious subatomic particles are zooming around like faster-than-light roaches. Eerie.

I love the word **maria**. When pronounced Ma-RYE-uh, as in Mariah Carey, it's the first name of the great observer Maria Mitchell (1818–1889). She blazed a trail for women astronomers from her observatory on Nantucket Island in Massachusetts (worth a visit), then as a Vassar College professor. But pronounced differently, as MAR-ee-uh, they're the black lava seas on the Moon, the most prominent lunar features visible to the naked eye.

What about your own favorites? Send them in, and we'll do a reprise within a year with reader suggestions. This is fun.

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BY GLENN CHAPLE

The "wow" factor

In spring 1993, I hosted an informal

star party for a group of my 8th-grade science students. Following the "wow" principle described here last month, I began with the Moon. As expected, the students' first close-up views of this magnificent, cratered world elicited gasps of awe and wonder. Next on the docket was Jupiter. The "wows" continued when I informed the fledgling skygazers that the banded disk they were looking at could hold 1,300 Earths.

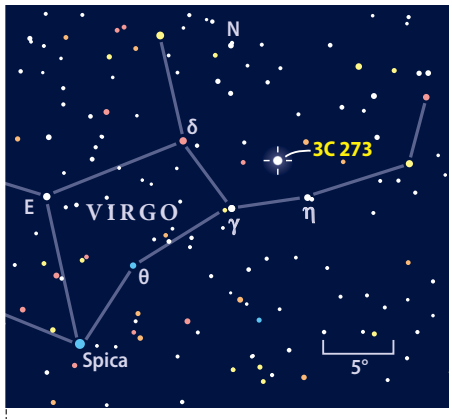
Eventually, the group dwindled until only a handful of students remained. I had a special treat in mind for these die-hards. Several weeks earlier, a supernova had erupted in the galaxy M81. It shined at 10th magnitude — a speck no different in appearance than some foreground Milky Way stars. Visually, it wasn't too impressive. Would knowledge of what they were looking at "wow" them? I gave it a try.

"Would you like to see a supernova?" I asked the group. The opportunity to view firsthand something they had learned about in science class was too good to pass up. I warned them they would be looking at an ordinary, starlike point of light, not something as spectacular as the exploding Death Star in *Star Wars*.

When the first student peered into the eyepiece, I asked if he could see a fuzzy oval blob. This, I told him, is the nucleus of M81 — a galaxy 11 million light-years away. I then directed his attention to a triangle of stars close to the nucleus.

"See the star in the triangle that's farthest from the other two?" I prompted. "That's the supernova. The other two are Milky Way stars just a few hundred light-years away at most. The supernova lies on the outer edge of M81. You're looking at a star that exploded 11 million years ago!"

There was a moment of silence, followed by a long "Wwwowww!" Credit that "wow" to his newfound knowledge of the object he was looking at.



THIS FINDER CHART gets you in the vicinity of 3C 273. For a more detailed map to this distant quasar, visit www.aavso.org. *ASTRONOMY:* ROEN KELLY

This month, I'd like to introduce you to a cerebral "wow" object that puts the M81 supernova to shame — 3C 273. As the brightest and one of the nearest quasars, it appears as an obscure 13th-magnitude star through a telescope. Even though I've glimpsed it in a 4-inch reflector, 3C 273 appears better when viewed in a scope at least 6 inches in aperture.

3C 273 lies in the constellation Virgo, a short star-hop from the star Eta [η] Virginis. The AAVSO "b" chart for the variable star SS Virginis maps the route nicely. To get a copy, go to the AAVSO web site at www.aavso.org. Click on "Charts" on the left side of the screen, and then type in "SS Vir" in the box next to "Name." Select the "B(GIF)" chart — or "BR(GIF)" if you have a refractor or Catadioptric scope whose star diagonal produces a mirror image. To pinpoint your target, you'll also need the AAVSO "D" chart for 3C 273.

As you gaze at this tiny point of light, ponder its significance. A quasar is the active core of a distant galaxy. Possibly no more than a few light-months across, 3C 273 releases as much light as 10 trillion Suns — 100 times the output of the entire Milky Way Galaxy. This output's source seems to be a supermassive black hole at the galaxy's core that releases incredible quantities of light as it swallows up surrounding gas and unfortunate stars.

If 3C 273 were 32 light-years away (about the same distance as the star Arcturus), it would shine in our sky as brightly as the midday Sun. At its distance of 2 billion light-years, it's the most remote object visible in ordinary telescopes. The light collected by your telescope and transported to your eyes left this quasar at a time when the dominant life-forms on Earth, single-celled organisms, drifted about in the Precambrian ocean. Larger earthly life-forms, like worms and jellyfish, were still a billion years from existence. Wow!

For those of you who don't yet have the observing know-how to star-hop your way to 3C 273, or lack a telescope big enough to capture it, a familiar friend awaits — Jupiter. The planet that has captivated astronomers since Galileo's time (1564–1642) will put on a grand show in even the smallest telescope. Low power (30x–50x) will reveal Jupiter's slightly flattened, banded disk. With this same magnification, you can see the planet's four bright Galilean moons. Think of this as you gaze: If our Earth were "out there" with this colossal planet, it would be just another of Jupiter's moons — brighter than the others, but still just a moon. Wow!

Next month: building your own telescope, and we visit Stellafane. Clear skies.

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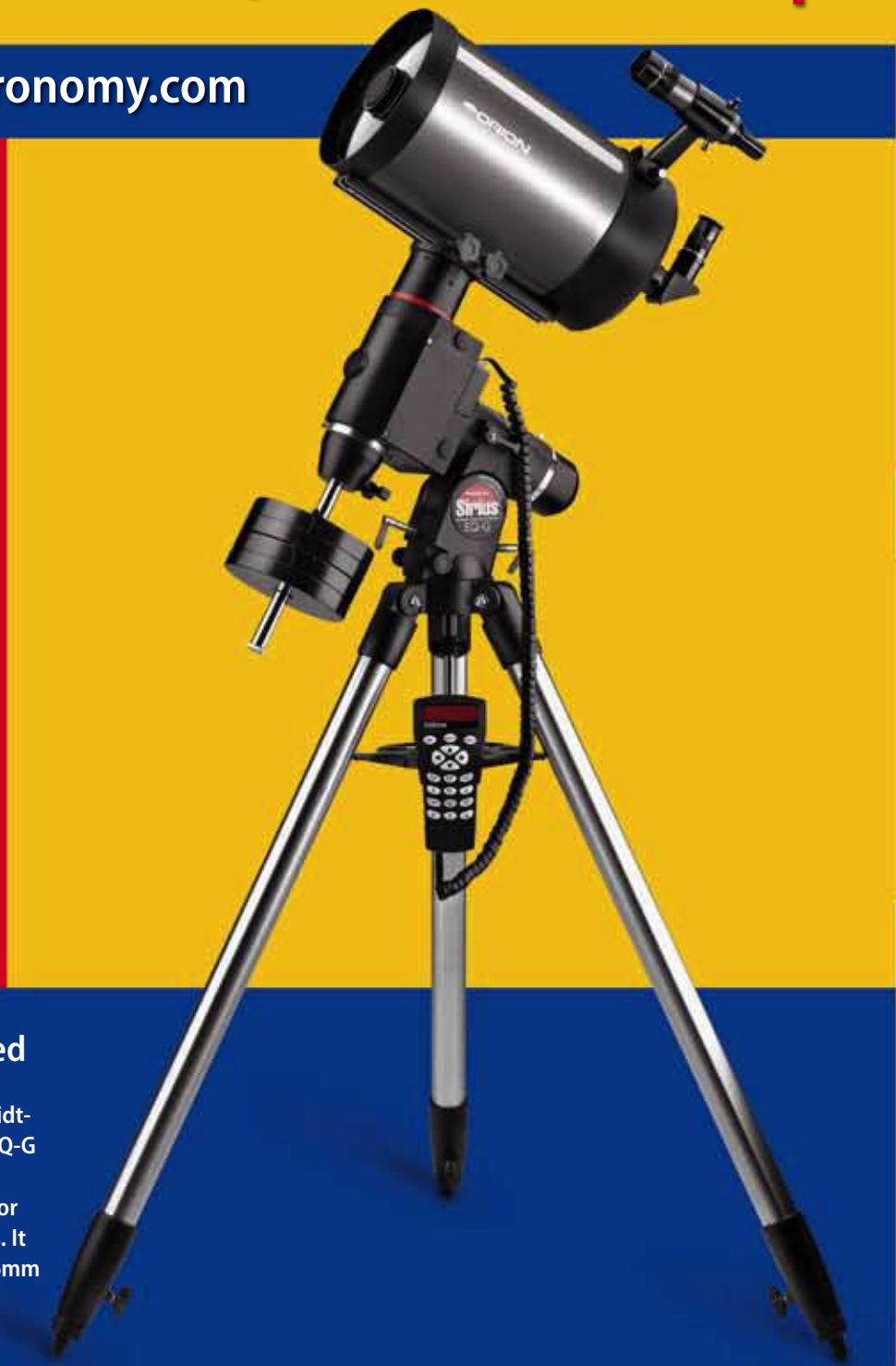

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Sweepstakes Entry. To enter, complete and mail the official entry form or a postcard with name, address, city, state or province, zip and telephone number on a postcard and send it to: *Astronomy* Summer 2006 Sweepstakes, P.O. Box 378, Waukesha, WI 53187-0378. Or enter online at www.astronomy.com by filling in the Online Entry form and hitting the SEND key. The Online Entry form must be filled out completely to be eligible. Incomplete or defaced entry forms are void. One entry per household. The official ending date for the *Astronomy* Summer 2006 Sweepstakes is July 14, 2006, and all entries must be transmitted or postmarked no later than that date.

Prizes and Odds of Winning. One drawing will be held on or about September 12, 2006, for the following awards: One Grand Prize consisting of an Orion Sirius 8 EQ-G GoTo Schmidt-Cassegrain (retail value $1,899.95). Two First Prizes consisting of an Orion SkyQuest™ XT8 IntelliScope® and hand controller (retail value $599.95). Three Second Prizes consisting of an Orion StarShoot™ Deep Space CCD Color Imaging Camera (retail value $399.95). Four Third Prizes consisting of an Orion SkyLine™ Green Laser Pointer (retail value $99.95). Cash equivalents of merchandise will not be awarded. Substituting prizes is not allowed. Any applicable federal, state and/or local taxes are the responsibility of the winner. Odds of winning depend on the number of entries received. Total circulation for *Astronomy* magazine is 130,601. Sweepstakes void in Quebec and void where prohibited.

Validation and Acceptance. Winners in the *Astronomy* Summer 2006 Sweepstakes will be selected in a random drawing conducted by an independent judging organization whose decisions are final. Canadian prize awards subject to skill test requirement. By entering the sweepstakes, participants agree to be bound by these official rules and all decisions of the judging organization. Sweepstakes entries void if not legible, not completed in full, not obtained legitimately, or if forged, photocopied, mechanically reproduced, late or tampered with. The potential winners must sign and return an Affidavit of Eligibility, publicity release and Release of Liability within fourteen (14) days of notification. In the event of noncompliance, alternate winners will be randomly drawn. No responsibility is assumed for lost, stolen, misdirected or late entries or notifications. All sweepstakes entries become the property of the sponsor and will not be returned.

Winner's List. For a list of winners, send a stamped, self-addressed envelope to: *Astronomy* Summer 2006 Sweepstakes Winners List, P.O. Box 1612, Waukesha, WI 53187-1612. Residents of FL, VT and WA may omit stamp. Requests must be received by October 12, 2006. Or check the *Astronomy* Web site (www.astronomy.com) after November 11, 2006.

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BY PHIL HARRINGTON

The Big Dipper, part two

Ready to return to the sky's most famous star pattern, the Big Dipper? Last month, we visited several deep-sky sights lying near the bowl. This time out, we'll tour the Dipper's crooked three-star handle.

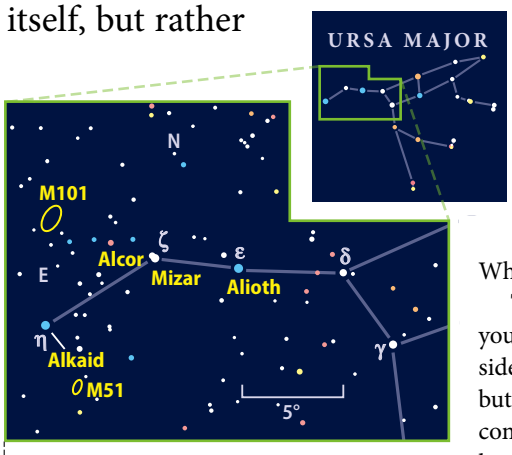
The Big Dipper is not a constellation by itself, but rather part of Ursa Major the Great Bear. The Dipper's bowl forms the Bear's back and belly, while artists often portray the three stars in the Dipper's handle — **Alioth**, **Mizar**, and **Alkaid** — as its long tail. But bears don't have long tails.

A better explanation comes from a Native American legend that depicts the tail stars as three hunters chasing the bear. In fact, if you look carefully, you can see that the hunter in the middle is carrying a pot to cook the bear in after they catch it.

The "pot" is the star **Alcor**. With Mizar, they form one of the sky's best-known double-star teams. They make a fun naked-eye test and are an easy target for even the smallest binoculars. Mizar shines at 2nd magnitude, while Alcor glows at 4th.

They may look like a physical pair, but Alcor and Mizar are actually frauds. Mizar lies 78 light-years from us, while Alcor is 81 light-years away. Mizar turns out to be a true close-set binary star, but you'll need a telescope to see its companion.

Don't confuse that for a third, fainter star that forms a tiny triangle with Alcor and Mizar. Although this star is not physically related to either, it holds an interesting footnote in astronomical history. In 1722, German mathematician Johann Liebknecht thought he saw this star move against the background from 1 night to the next. He concluded it was not a star, but a new planet. In his excitement, he christened it Sidus Ludoviciana ("Ludwig's Star") after Ludwig V, then king of Germany. It quickly became apparent that Liebknecht was mistaken, but the star is still called Sidus Ludoviciana.



THIS STAR MAP will help you navigate your way through the Big Dipper.
ASTRONOMY: ROEN KELLY

Now, let's go hunting for bigger game. From Mizar, trace a zigzag of four faint stars eastward, away from the curving handle. At the fourth star, hook a little to the northeast, toward a diamond of four fainter stars. Can you see a faint smudge next to the diamond's eastern point? That's the famous spiral galaxy **M101** — a challenging target for small telescopes, let alone binoculars. Even with averted vision, M101 probably will seem little more than a dim glow, but ponder what you are looking at — a system of billions of stars. The light from these stars left 27 million years ago, long before our earliest ancestors evolved on the grassy savannahs of eastern Africa.

If M101 proves a little too tough, try your luck with a brighter galaxy. Aim toward Alkaid, the star at the end of the Dipper's handle. Look half a field to Alkaid's west-southwest for a 4th-magnitude star, and then, from there, move an equal distance farther south to a pentagon of dimmer suns. If you look carefully just inside the pentagon's eastern corner, you might spot a dim glow. That's **M51**, the beautiful Whirlpool Galaxy.

Through 70mm and larger binoculars, you might notice M51 appears a little lopsided. You aren't looking at just one galaxy, but two. Charles Messier missed M51's companion, so you won't find it in his catalog. We know it today as NGC 5195, its listing in the *New General Catalogue*. NGC 5195 glows at about 10th magnitude.

Let's wrap things up with a reminder. In the March issue, I mentioned how Saturn was near M44, the Beehive Cluster in Cancer. The pair continues to form a pretty sight through binoculars. As a bonus, the crescent Moon joins them May 31. All three will fit nicely into the same binocular view as the sky darkens after sunset.

Be sure to drop by Astronomy.com this month for more binocular targets around the Big Dipper's handle. Then, come on back next month. We'll visit the sky's strongman, who has a few celestial surprises of his own. Till then, remember: Two eyes are better than one.

ONLINE EXTRA More targets lurk around the Big Dipper's handle. To find out where, visit www.astronomy.com/toc.

Science and Religion: age-old adversaries, or partners in the search for truth?

Explore centuries of scientific and theological thought in 12 riveting half-hour lectures

Two crucial forces have helped shape Western civilization and continue to interact in our daily lives. Contrary to prevailing notions that they must perpetually clash, science and religion have actually been partners in an age-old adventure.

Professor Lawrence M. Principe unfolds a surprisingly cooperative dynamic, in which theologians and natural scientists share methods, ideas, aspirations, and a tradition of disputational dialogue.

St. Augustine warned that it is dangerous for religious people to ignore science: "Many non-Christians are well versed in natural knowledge, so they can detect vast ignorance in such a Christian and laugh it to scorn."

On the other hand, Sir Isaac Newton freely discusses the attributes and activities of God in *Principia Mathematica,* which sets forth his theory of gravity and laws of motion.

These examples represent the traditional relationship of science and religion that is too often obscured by the divisive, hot-headed rhetoric and the gross oversimplifications we often see in today's headlines. Long before the shouting and the sloganeering, scientists and theologians have pursued a unity of truth, and most theologians have agreed with the advice of Galileo's colleague, Cardinal Baronio, that the Bible "tells us how to go to heaven, not how the heavens go."

Once we understand this, we have a new perspective on many present-day controversies. The current antievolution furor, for example, centers on the fixation that Genesis 1 should be taken literally, an issue that had been resolved by theologians long ago. Professor Principe deems it "astonishingly trivial," and shows how science gives theologians powerful tools for enriching, not contradicting, their understanding of ultimate truths.

The Search for Answers

Moving from the early centuries of the Christian era and the Middle Ages to our own day, he exposes the truth about the Galileo Affair and provides a revealing picture of the circuslike Scopes Trial. You will hear St. Augustine's profound ideas about reason and faith, and meet a 19th-century writer whose anti-Catholic diatribe spread myths that persist today.

About Your Professor

Dr. Lawrence M. Principe is Professor of the History of Science and Technology, and Professor of Chemistry at Johns Hopkins University. He received a Ph.D. in Organic Chemistry from Indiana University and a Ph.D. in the History of Science from Johns Hopkins University. He has won several Johns Hopkins teaching awards and the 2004 Francis Bacon Prize from the California Institute of Technology.

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Sun storms Solar scientists say the Sun's next activity peak will be 30–50 percent stronger than its last one. The March 6 forecast comes from a new computer model of the Sun's workings.

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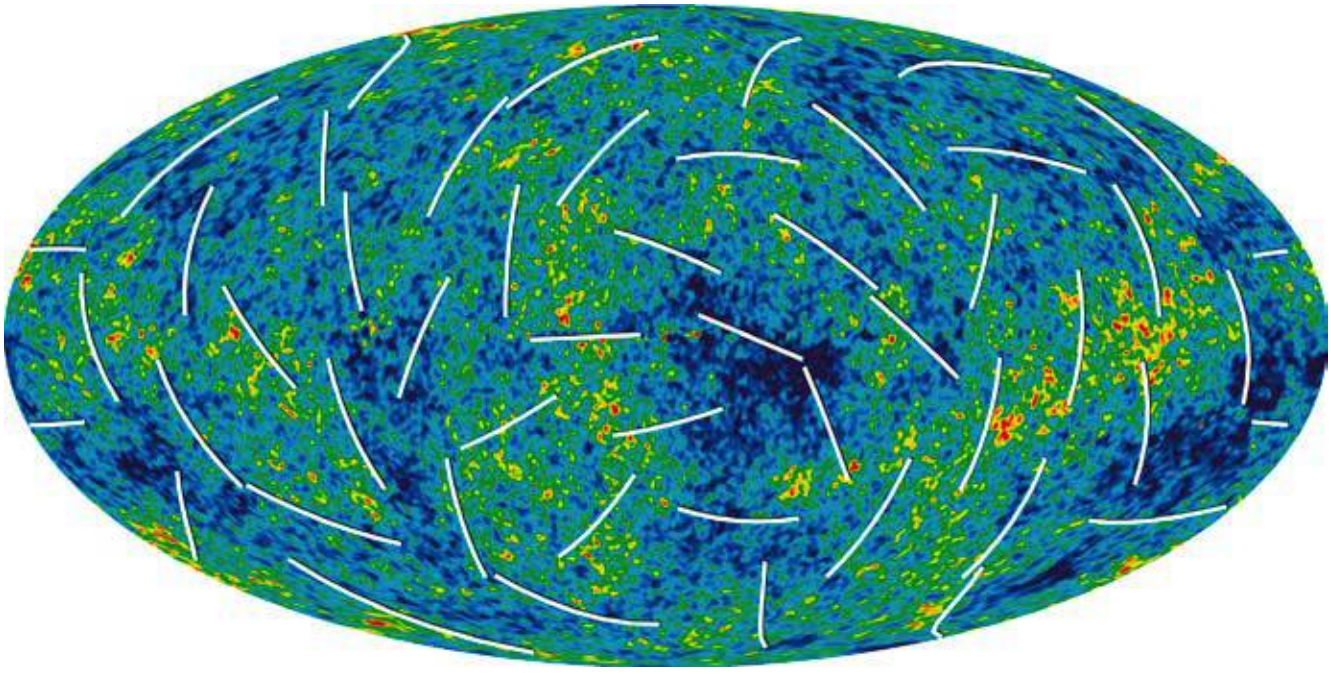

ORIENTED LIGHT. The WMAP team has measured the preferred direction (white bars) of radiation in the cosmic microwave background. Scientists say the results indicate inflation followed the Big Bang. NASA/WMAP SCIENCE TEAM

WMAP spies inflated cosmos

New data from NASA's Wilkinson Microwave Anisotropy Probe (WMAP) give cosmologists a glimpse of the universe within its first trillionth of a second. Scientists say the new WMAP release provides the first direct evidence that a period of inflation followed the Big Bang.

WMAP previously measured subtle temperature changes in the cosmic microwave background (CMB). This time, the focus is on the radiation's preferred direction (polarization).

The CMB polarization signal, the weakest cosmological signal ever detected, is roughly 100 times fainter than the temperature signals WMAP measured 3 years ago. Light from the very early universe is not polarized, but the first generation of stars reflected and polarized the Big Bang's afterglow (the CMB).

In WMAP's first year, scientists couldn't separate the effects of light scattering caused by the first stars from the effects of inflation. The polarization measurement, however, is sensitive only to the first stars, so scientists can now separate the two.

Scientists can now "look at brightness patterns from inflation and know it's from inflation and not from the first stars," says WMAP's principal investigator Charles Bennett of Johns Hopkins University.

Inflation theory holds that tiny fluctuations in the early universe rapidly magnified into larger fluctuations, which later evolved into modern structure. In the simplest inflation scenarios, differences in the CMB's brightness vary with fluctuation size. This is what WMAP found. It provides direct evidence inflation occurred in the early universe and rules out more complex inflation models.

WMAP's new results indicate the first stars formed some 400 million years after the Big Bang — about twice the time previously believed.

The new data also help scientists refine their understanding of the universe's contents: 4 percent is ordinary matter, 22 percent is dark matter, and 74 percent is dark energy.

— LIZ KRUESI

24 **It's tricky launching a satellite from a satellite**

26 **Butterfly on Mars**

28 **Cassini spots Saturn storm**

You'll Like What You See ...

About Vixen

Vixen astronomical products have been treating their owners to the delight of the night sky since 1949. Always respected by quality minded amateurs, Vixen today offers some of the latest technology encased in the solidity of the past. Take the "goto" SPHINX mount and STAR BOOK; a sturdy German equatorial mount for all types of scopes combined with the first electronic star chart hand-controller. The SPHINX is just one example of Vixen's ingenuity on display at Certified Stocking Vixen Dealers and in stock for you to take home and enjoy tonight.

GP-D2 Equatorial Mount

Deluxe Equatorial Mount

Geared for those seeking a portable, high-precision mount for astrophotography or simply visual observing, the GP-D2 is the perfect platform for more than just Vixen telescopes! Accurate tracking is achieved with dual 144-tooth brass worm wheels and gears. The R.A. worm is machined to 0.001 mm tolerance for accurate tracking, and all worm gears are individually inspected before assembly in Japan. Die-cast aluminum pares the weight of the GP-D2 down to 18.7 lbs. yet the design permits a carrying capacity of 22 lbs. Manual slow motion controls are provided.

R200SS 8" f/4 Richfield Newtonian

Advanced Imaging & Visual

At f/4 there's no room for error when forming the surface of a parabolic mirror. Vixen's solution is to execute each R200SS mirror with its High-Precision Poly-Order Aspherical Mirror Molding Technique. The result: exquisite state-of-the-art paraboloid form. Compact 28" length and only 11.7-lbs, the large 60mm drawtube allows for a whopping 2.6° x 1.7° field-of-view on 35mm format. The perfect imaging mate for the GP-D2 equatorial mount.

Recommended Accessories

Coma Corrector

Eliminates coma in full-frame imaging. Can be left on for visual use.

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SPHINX Equatorial Mount

"Vixen's newest go-to mount is a winner." — Astronomy

SPHINX mount with its Internet upgradable STAR BOOK controller, is the culmination of a decade of design experience. SPHINX responds nimbly and precisely to your commands due to its lightweight design with low-rotational momentum. STAR BOOK is striking with its 4.7" LCD screen and powerful CPU that produces localized star charts with Constellations, "goto" menus for 22,725 celestial objects: Messier, NGC/IC, Solar System, stars, and more. Auto-guider port works with SBIG guiders. Mount is controllable through popular planetarium programs such as *TheSky6* (*Serious* or *Pro*) and *Starry Nights* (*Pro* or *Pro Plus*).

The Reviews are In: "A telescope mount for the 21st century"
***Astronomy* magazine, November 2005**

- "The Star Book is so easy to operate it flirts with user-interface perfection ... ."
- "As it stands now, the Sphinx is by far the easiest-to-use go-to mount."
- "Those interested in imaging should give this mount consideration."
- "The Sphinx is an extraordinary value because this amount of periodic error is normally encountered only in mounts 4 or 5 times its cost."
- "More good news: The mount is terrific."
- "To its credit, the screen worked well even at low temperatures — I subjected it to a test at -15° Fahrenheit (-26° Celsius) one night... ."

Recommended Accessories

Polar Axis Scope

Aluminum Case

Holds SPHINX, STAR BOOK, weights, battery case and more.

Tripod Carry Bag

Includes half-pillar pouch.

PORTA Alt-Az Mount

PORTA: Exceptionally Portable Mount!

Newly designed friction system for quickly pointing toward the object and hand tracking it with the 360° slow-motion controls. No fumbling with clutches or sectional slow-motion controls! Leave the counter-weights with the equatorials: simply balance scopes up to 9-lbs. on the altitude axis and start viewing! Standard Vixen dovetail mounting slot with lock and safety screw is fully SPHINX/GP-compatible. PORTA mount features interchangeable slow-motion knobs, tension adjustment and disassembly tools, built-in tool storage bay, tripod tray and aluminum legs.

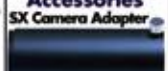
ED80Sf 80mm f/7.5 APO Refractor

Portable Affordable APO

Breakthrough price on an ED80Sf scope package including giant 9x50mm finder, dual T-thread flip-mirror with 1¼" eyepiece adapters, rotatable 2" eyepiece adapter with locking collar, Crayford focuser with tension/lock adjustment, tube rings with dovetail plate and telescope/accessory travel case! Included standard accessories make the ED80Sf the value leader in affordable 80mm APO scopes. Perfect size for PORTA mount makes this an exceptionally portable system.

Recommended Accessories

SX Camera Adapter



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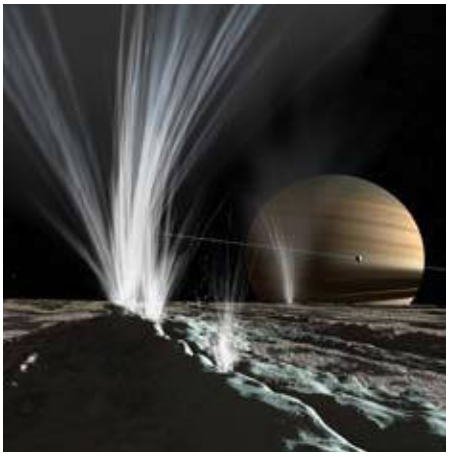


RON MILLER

ICY SPRAY. **Cassini scientists think plumes of water and ice erupt from Enceladus' surface.**

Water geysers on Enceladus

High-resolution images of Saturn's moon Enceladus provide evidence that liquid water is erupting in geyser-like fashion near the tiny moon's south pole. NASA's Cassini spacecraft gathered the data last year when it flew by the moon 3 times.

Cassini imaged fractures at the south pole, dubbed "tiger stripes," venting water-vapor plumes some 265 miles (430 kilometers) into the atmosphere. Scientists believe heated subsurface pockets of liquid water drive the eruptions, although what's heating the moon so much is unknown. Other interpretations, they say, cannot explain Cassini's observations.

"We have found another environment in our solar system, in a very surprising place, that could host living organisms," says Carolyn Porco of the Space Science Institute in Boulder, Colorado, and the Cassini Imaging Team leader.

Life as we know it requires liquid water, a heat source, and organic material. At Enceladus, all three appear to exist. Scientists caution that any life there would be microbial, similar to organisms living near hydrothermal vents on Earth.

Enceladus joins a select group of solar-system places with active geology: Earth, Jupiter's moon Io, and Neptune's moon Triton. **— LAURA BAIRD**

It's tricky launching a satellite from a satellite

Launching a satellite into orbit from the ground is hard enough, but launching one from a platform already in space is an entirely different problem. An astronaut aboard the International Space Station (ISS) demonstrated this February 3 when he jettisoned an amateur-radio-in-a-spacesuit named SuitSat.

The crew outfitted a surplus Russian Orlan spacesuit with batteries, sensors, and a radio transmitter. SuitSat faintly broadcast recorded voices of school children to amateur radio operators worldwide until February 18.

Although space may have no up or down, it turns out there's only one good direction for throwing away anything from ISS. Not following this rule means a discarded object may return and collide with the space station.

Cosmonaut Valery Tokarev shoved SuitSat from a Russian airlock opposite ISS' motion. Television views showed the suit shrinking in size as it floated above Earth's horizon. But then SuitSat fell below the horizon and appeared against the moving Earth below. Where was it going?

Tokarev threw SuitSat such that its average orbital speed was less than ISS', so SuitSat followed Newton's laws and moved to a slightly lower altitude. Within 10 minutes, SuitSat lost its relative backward motion and settled into its lower orbit. Ten minutes later, it passed about 2,000 feet (610 meters) beneath the station, pulling ahead.

This separation profile may have seemed scary, but it was safer than any alternative. The laws of orbital motion have logical — but unearthly — consequences for departures in any other direction.

Throwing SuitSat straight down would have been the worst choice. This makes no practical change in the object's total speed, so its orbit would parallel the station's. SuitSat would have dropped for a few minutes and then begun pulling ahead. But with its absolute speed undiminished, it would begin to coast "uphill" and soon cross a mile or so in front of ISS. It would continue to rise, slip backward, fall again — then smash into ISS opposite the side it departed from.

NASA

CASTAWAY. **Space-station crew members released a spacesuit-turned-satellite called SuitSat February 3, 2006.**

Throwing SuitSat straight up is a mirror image of the same problem, with similar results. And throwing sideways causes the object to come "boomeranging" twice as fast as in the up-or-down cases. The reason: The out-of-plane motion makes an orbit slightly inclined to ISS', which means their paths intersect twice on every circuit.

A forward throw makes a higher, slower orbit, so SuitSat would have passed and disappeared behind ISS. Air drag would have caused it to slip into a lower, faster orbit, overtake the station, and threaten to strike at a speed much greater than when it left.

In early 2001, NASA had to move the entire space station when a dropped tool took that path and came whizzing back a few days later. That's what comes from overlooking Newtonian mechanics in space. **— JAMES OBERG**

Sahara impact

Boston University's Farouk El-Baz announced March 3 his find of a 19-mile-wide (31 kilometers) impact crater in the Sahara Desert on the Egypt-Chad border. Kebira Crater, the Sahara's largest, is at least 100 million years old.

Venus Express wants you

Since May, when the European Space Agency's (ESA) Venus Express settled into orbit around Venus, the probe has been scrutinizing the cloudy planet. But if you're an astroimager, project scientists want your help, too.

Venus Express' Venus Monitoring Camera (VMC) images the planet across a broad span of wavelengths, from the near-ultraviolet to the near-infrared. But VMC isn't able to monitor Venus continuously. Sometimes, ground-based telescopes may be able to view parts of the planet the spacecraft cannot.

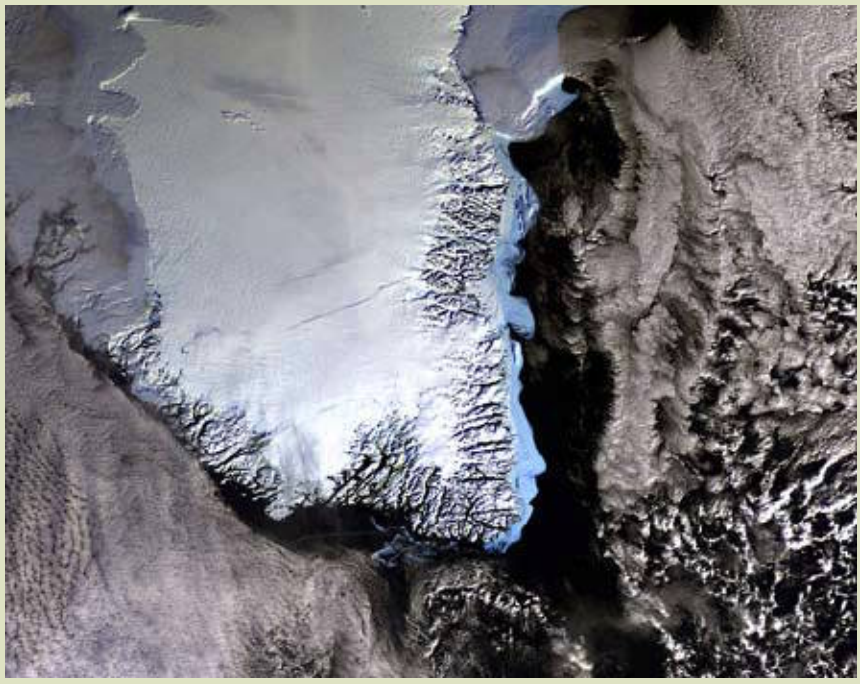
The Venus Express Ground Observing Project is counting on advanced amateurs to acquire filtered images of the planet's atmosphere. The project's plans include observing campaigns around each Venus apparition and during specific periods to best coordinate with the spacecraft. See the European Space Agency's web site (sci.esa.int) for details. — **FRANCIS REDDY**

Exiled from the Milky Way

Using the Multiple Mirror Telescope (MMT) atop Arizona's Mount Hopkins, a team led by Warren Brown of the Harvard-Smithsonian Center for Astrophysics (CfA) has found two stars moving so fast they'll escape the Milky Way.

One star has a mass of about 4 Suns, lies some 240,000 light-years away, and is moving at about 1.25 million mph (2 million km/h). The second castaway has the same mass, is some 180,000 light-years from Earth, and is streaking through space at 1.43 million mph (2.3 million km/h).

The team discovered the first stellar exile in 2005. To date, Brown and colleagues have found three exiles, and European groups, two. — **LAURA LAYTON**



ESA

FAST ICE. **Envisat imaged south Greenland February 16. The region's glaciers are dumping ice into the sea twice as fast as they did a decade ago.**

Greenland ice is melting fast

Greenland's southern glaciers are depositing twice as much ice into the Atlantic Ocean as they did a decade ago. Eric Rignot of NASA's Jet Propulsion Laboratory in Pasadena, California, and University of Kansas scientist Pannir Kanagaratnam measured glacier velocities using a suite of satellites: the European Space Agency's European Remote Sensing satellites ERS-1 and ERS-2, its Envisat Advanced Synthetic Aperture Radar, and Canada's Radarsat-1.

The study appeared in the February 17 issue of *Science*. The report joins other recent research indicating the Antarctic ice sheet and glaciers in Bolivia, Tibet, and on Mount Kilimanjaro in Tanzania now are losing mass.

Greenland's ice sheet, the second-largest concentration of frozen freshwater on Earth, has an area of 695,000 square miles (1.8 million square kilometers) and averages 1.4 miles (2.3 kilometers) thick. Scientists estimate its complete meltdown would raise sea levels by as much as 23 feet (7 meters). — **F. R.**

Spitzer snaps NGC 4579

Mature stars gleam blue while dusty star-forming regions glow red in this Spitzer Space Telescope image of NGC 4579. In this false-color composite taken with Spitzer's Infrared Array Camera, warmer colors indicate longer infrared wavelengths: Blue corresponds to emission at 3.6 microns, green to 4.5-micron emission, and red to 5.8 and 8.0 microns. The spiral galaxy lies 70 million light-years away. — **L. L.**

NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/R. KENNICUTT

BLUE NOTE. **NGC 4579's star dust gleams.**

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SHALLOW STRIKE. Scientists say an oblique impact caused this crater's unique shape.

Butterfly on Mars

The European Space Agency's (ESA) Mars Express spacecraft's High Resolution Stereo Camera (HRSC) captured this image of an elliptical, butterfly-shape impact crater in Mars' Hesperia Planum region. Unlike most impact craters, the butterfly's elliptical shape suggests an oblique impact angle of less than 10°. Scientists think the impacting body likely traveled in the direction of the crater's length. The crater is 15 miles (24 km) long, 7 miles (11 km) wide, and 2,130 feet (650 meters) deep. — **L. L.**

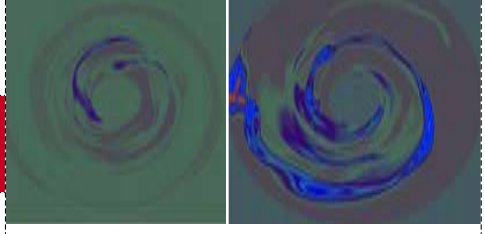
Shuttle Atlantis to be "parts donor"

NASA plans to retire space shuttle Atlantis after mid-2008. Discovery and Endeavour would fly the remaining missions to complete construction of the International Space Station, with Atlantis supplying any replacement parts the two working orbiters may need.

SPARE PARTS. NASA will start cannibalizing Atlantis in 2008. NASA

Atlantis is due for maintenance in 2008, a process that can take up to 2 years. With retirement of the entire fleet looming in 2010, Atlantis might fly only one mission after returning to service. "So, it looks like the right thing to do is … use it as a parts donor, if that's the word, for the other vehicles," says shuttle program manager Wayne Hale.

Atlantis may make up to five flights to the International Space Station before retirement. NASA expects the new Crew Launch Vehicle and Crew Exploration Vehicle to be ready no later than 2014. — **F. R.**



PLANET CLUMPS. Jupiter-mass clumps (dark blue) form more readily in a binary star system (right) than around a single star (left). CARNEGIE INSTITUTION OF WASHINGTON/ALAN BOSS

Binary stars may make more planets

New computer simulations of planet formation show that binary stars can build planets in a manner similar to single stars like the Sun. In fact, binaries may even do it better.

Astronomers had assumed that the more complex gravitational environment of multiple-star systems would interfere with the growth of protoplanets. But when Alan Boss of the Carnegie Institution of Washington simulated the process in single and multiple systems, he found that stellar companions helped encourage density enhancements that could develop into planets.

"We tend to focus on looking for other solar systems around stars just like our Sun," Boss says. "But we are learning that planetary systems can be found around all sorts of stars, from pulsars to M dwarfs with only one-third the mass of our Sun." His findings will appear in *The Astrophysical Journal*. — **L. L.**

Satellite falls silent

Despite efforts from ground controllers, NASA's Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite has been floating unresponsive in Earth orbit since December 18, 2005. However, controllers have one last trick to bring IMAGE around.

According to mission scientist Tom Moore, a full power-off restart might fix the problem. But this isn't so easy to do: The solar-powered satellite must be completely in the dark. The next opportunity occurs in October 2007, when IMAGE is at its farthest point from Earth and passes slowly through the planet's shadow.

Launched March 25, 2000, IMAGE operated more than twice as long as expected. The satellite helped scientists better understand how space plasma interacts with Earth's magnetic field. — **MATTHEW QUANDT**

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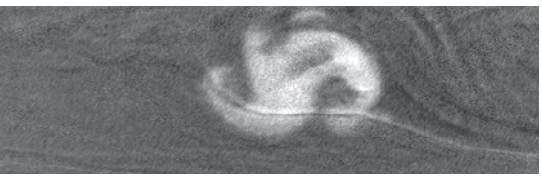


NASA/JPL/SSI

PERFECT STORM. Cassini's imaging team captured Saturn's superstorm in light reflected from the planet's rings.

Cassini spots Saturn storm

On January 23, the Cassini spacecraft detected cracks, pops, and other radio noise from a giant storm in Saturn's atmosphere. The noise came from lightning bolts 1,000 times stronger than anything seen on Earth.

"This is the strongest lightning activity that we've seen yet with Cassini since it has arrived at Saturn," says the University of Iowa's Don Gurnett, principal investigator for Cassini's Radio and Plasma Wave Science (RPWS) instrument.

Andrew Ingersoll, a member of the Cassini imaging team, says the spacecraft's view of Saturn's night side would allow its cameras to detect lightning; but Saturn's rings reflect so much light onto the planet's clouds, any optical flashes are washed out.

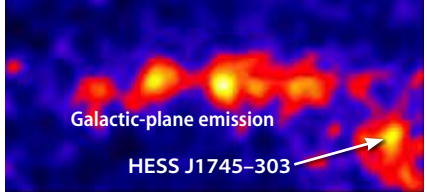
Sunlight at Saturn is 100 times dimmer than at Earth due to the ringed planet's 10-times-greater distance from the Sun. Nevertheless, says Ingersoll, the light the rings cast onto Saturn's cloud tops is 10 times brighter than that of a Full Moon on Earth. But while "ringshine" obscured lightning flashes, it was bright enough to let Cassini's cameras image the storm. — **F. R.**

BRIEFCASE

Main-belt comets

The asteroid belt holds a new class of comets, say David Jewitt and Henry Hsieh at the University of Hawaii. "Main-belt comets" include asteroid 118401, from which the team measured comet-like dust emission last November, and two comets in asteroid-like orbits. In a March 23 report published online by *Science*, the team says such ice-rich rocks may have delivered early Earth's water. — **F. R.**

HESS finds galactic-center gamma rays



HESS PROJECT

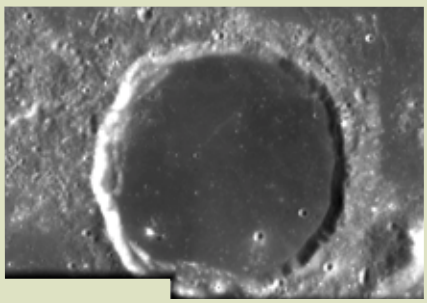
GLOWING BAND. High-energy gamma rays radiate away from the galactic center.

Astrophysicists using the High Energy Stereoscopic System (HESS), an array of four gamma-ray telescopes in Namibia, have discovered high-energy gamma rays coming from gas clouds near the Milky Way's center.

Researchers believe the clouds give off gamma radiation because cosmic rays — bare nuclei moving near light-speed — are racing through them. HESS scientists think the gamma rays they observe were produced by cosmic rays accelerated in a single supernova remnant during the past 10,000 years.

There are two possible cosmic-ray accelerators in the galactic center. The first is a supernova remnant known as Sagittarius A East, which scientists estimate is about 10,000 years old. The second is the supermassive black hole Sagittarius A*, which is quiet now but may have been more active in the past.

More observations are needed to pinpoint which is the cosmic-ray source, HESS researchers say. Their paper appeared in the February 9, 2006, issue of *Nature*. — **L. K.**



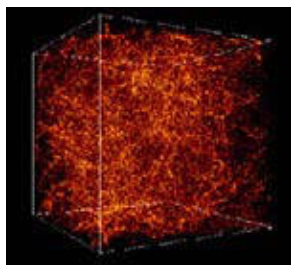
LAVA BOWL. Billy Crater is one of the Moon's darkest spots. ESA/SPACE-X

SMART-1 snaps Billy Crater

The European Space Agency's SMART-1 probe imaged the Moon's Billy Crater January 14. Dark mare material filled the crater after the impact. The crater is 28.6 miles (46 kilometers) wide and more than 0.8 mile (1.3 km) deep. It's located at 50.1° west, 13.8° south, at Oceanus Procellarum's southern edge. — **F. R.**

A simpler cosmic relation

University of Chicago astrophysicists have determined there is a simple way to model cosmic-structure evolution that matches observations: The scientists relate luminous matter today to dark-matter clumps in the early cosmos.



COSMIC BEAUTY. A computational model of structure evolution agrees with observation. ANDREY KRAVTSOV (U. CHICAGO) AND ANATOLY KLYPIN (NMSU)

The Chicago group — Charlie Conroy, Andrey Kravtsov, and Risa Wechsler — found a way to connect observable properties of today's galaxies, such as luminosity, to properties of dark-matter clumps (halos) in their simulations. Their findings imply the distribution of dark matter alone can explain the development of web-like cosmic structures.

The group's simulations cover the cosmic age from roughly 1 billion years after the Big Bang to today. They compared their model with the Deep Extragalactic Evolutionary Probe 2 (DEEP2) redshift survey, which observed cosmic structure at half the universe's age. The DEEP2 team found that brighter galaxies are more clustered, meaning they reside in more massive dark-matter halos.

These observations, combined with data from the Sloan Digital Sky Survey, agree with the galaxy-luminosity/halo-mass relation. Both sets of findings will appear in the June 20, 2006, issue of *The Astrophysical Journal*. — **L. K.**

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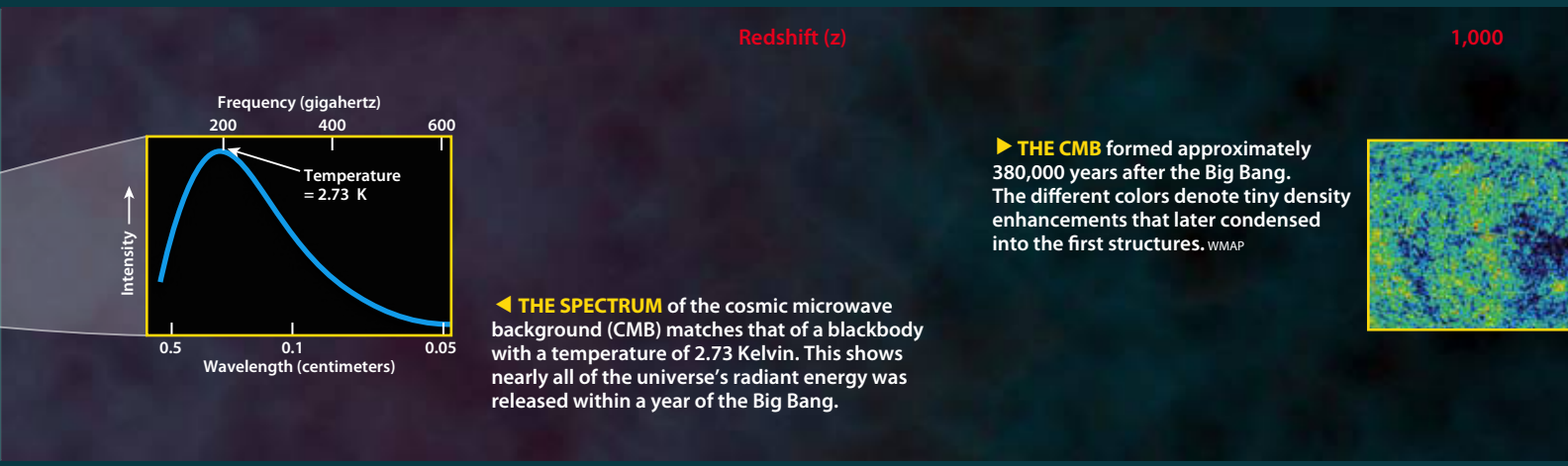
THE BIG BANG marks the birth of the universe, when space, time, and matter came into existence. ALL ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

The first billion years

After the release of the cosmic background radiation, darkness fell over the cosmos. /// **BY ADAM FRANK**



◀ **THE SPECTRUM** of the cosmic microwave background (CMB) matches that of a blackbody with a temperature of 2.73 Kelvin. This shows nearly all of the universe's radiant energy was released within a year of the Big Bang.

▶ **THE CMB** formed approximately 380,000 years after the Big Bang. The different colors denote tiny density enhancements that later condensed into the first structures. WMAP

Big Bang theory tells us the entire universe — all space, time, matter, and dimension — emerged from a single titanic explosion that set the cosmos in motion. Light brilliant beyond description flooded the infant universe.

There's a second part to the scientific story, however, that many people have not heard: Darkness soon returned with a vengeance. The cosmic Dark Ages began less than 1 million years after the Big Bang and lasted for a billion or so years.

For astronomers, the story is still coming into focus as more powerful telescopes and faster computers illuminate the full scope of cosmic history. Using these tools, astronomers are taking their first steps toward understanding the strange universe of the Dark Ages, a cosmos devoid of galaxies that started forming the earliest structures, with starlight shining for the first time.

Adam Frank *is a astrophysicist at the University of Rochester in New York and a member of* Astronomy*'s Editorial Advisory Board. He wrote "Seeing the dawn of time" in our August 2005 issue.*

Beginning at the beginning

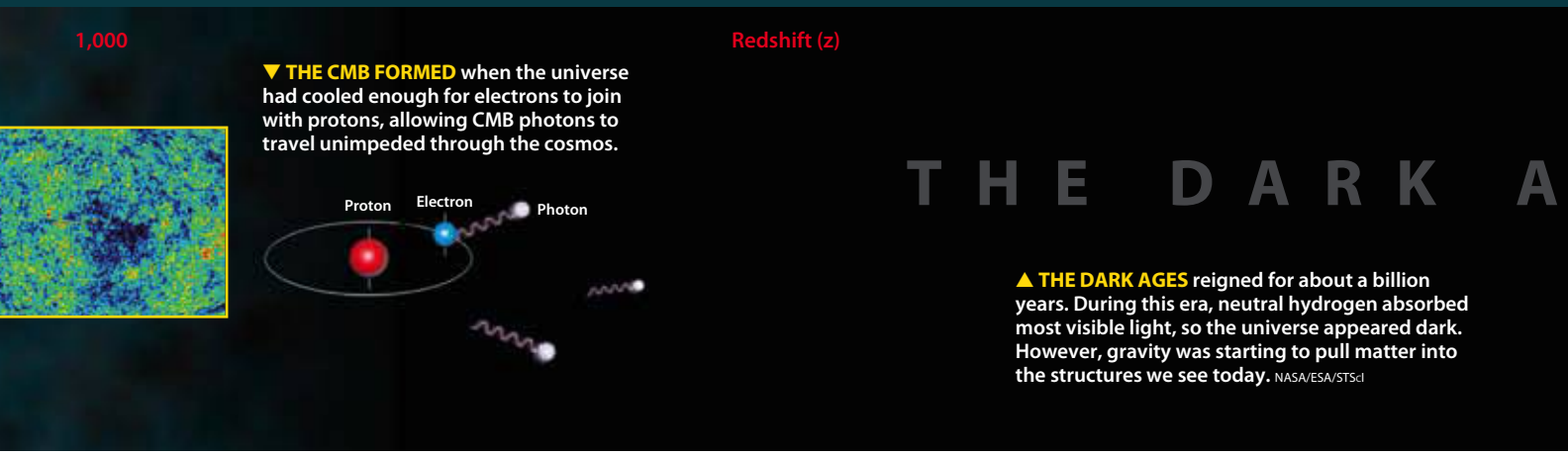
To understand the Dark Ages, we must briefly touch on the first epoch of light: the Big Bang. After this initial explosion, the universe was a smooth, hot, dense soup of exotic high-energy particles. Matter and radiation were mixed so closely that they shared a common temperature. In the parlance of physics, matter and radiation were strongly coupled. A photon could cross only a tiny fraction of the universe before being absorbed and then re-emitted by some particle of matter.

Then, as the universe expanded, it cooled, taking the particle-radiation mix through a series of dramatic transitions. They included the creation of protons and neutrons, building blocks of all atomic nuclei, about 1 second after the Big Bang. A scant 3 minutes later, the universe created the lightest nuclei: helium (2 neutrons, 2 protons) and a little lithium (3 protons, 3 neutrons).

During all these changes, matter and radiation remained strongly linked. After about 380,000 years, the universe had expanded and cooled to the point where electrons and protons could catch each other and bind into atomic hydrogen. This was the great parting of ways between matter and light. The birth of atomic hydrogen, the most abundant element in the universe, meant the end of one cosmic era and the beginning of the Dark Ages.

Astronomers often call the era when neutral hydrogen formed "recombination" because electrons and protons combined to form atomic hydrogen. It's a misnomer, however — this is the first time these atoms formed. In most stories of the Big Bang, the emphasis on this era lies with the sudden transparency of the universe to photons and the birth of the cosmic microwave background. When recombination occurred, photons previously linked to naked electrons and protons found themselves with nothing to interact with. They were free to expand unimpeded with the universe, with their wavelength stretching along with cosmic expansion. We see them today as relics of the Big Bang. If the still-smooth universe became transparent to photons and thus light, why does recombination signal the beginning of the Dark Ages? The answer lies with visual light, the kind our eyes respond to.

THE GOODS SURVEY uses advanced telescopes, including Hubble, Spitzer, and Chandra, to target a fairly empty region of space . The goal is to get a census of the universe and to probe back toward the beginning of cosmic structure. NASA/ESA



▼ **THE CMB FORMED** when the universe had cooled enough for electrons to join with protons, allowing CMB photons to travel unimpeded through the cosmos.

▲ **THE DARK AGES** reigned for about a billion years. During this era, neutral hydrogen absorbed most visible light, so the universe appeared dark. However, gravity was starting to pull matter into the structures we see today. NASA/ESA/STScI

While the neutral hydrogen gas could not absorb cosmic background photons, it efficiently absorbed visual and ultraviolet (UV) light. As soon as neutral hydrogen dominated the universe, visual and UV photons became trapped close to any source producing them. Most of the gas in today's universe is "ionized," meaning it consists primarily of bare hydrogen nuclei and free electrons. Stellar UV light maintains this ionization. These photons pack enough punch to tear electrons off any neutral hydrogen atoms that form by recombination. The current dominance of ionized hydrogen is one reason we can see so far with optical telescopes. The Dark Ages were the epoch of cosmic history between the initial formation of neutral hydrogen and its eventual destruction.

What was it, however, that illuminated the universe with the glow we now recognize as starlight? How did the cosmos go from a smooth, dark sea of neutral gas emerging from the recombination era, to the multitudes of stars and galaxies that dominate today? The Dark Ages mark an era of transitions, not only from blackness to light, but also from formlessness to form.

The universe at recombination was extraordinarily smooth. From detailed studies of the cosmic microwave background, astronomers know that any ripples, bumps, and lumps in the density of cosmic plasma were 1/10,000 as small as matter's average density. The universe we live in now bears little resemblance. Today's lumps and blobs — stars and galaxies — are far denser than an average volume of space, which is pretty close to a vacuum. The journey through the Dark Ages takes astronomers through the epoch when tiny, initial bumps, or perturbations, in the cosmic stew first began exerting their gravitational influence, feeding on surrounding gas in an effort to grow into the structures we see today.

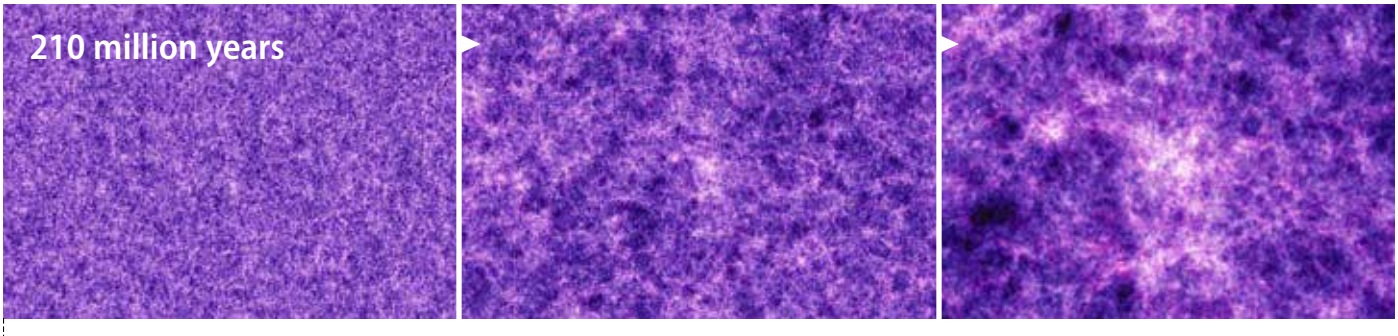
DID STRUCTURE FORM from the top down, or from the bottom up?

"There is tension in the early universe between expansion and collapse," explains Greg Bryan of Columbia University. Working with his former thesis advisor, Mike Norman of the University of California, San Diego, and Tom Abel of Stanford University, Bryan has pioneered using advanced computer simulations to study the formation of the universe's first structures.

In the absence of cosmic expansion, a lump of matter denser than its surroundings will draw in material at an ever-increasing rate. The denser the growing lump gets, the stronger its gravity becomes, and the faster it draws new material inward — a runaway collapse. The expansion of the universe changes this process. Just as gravity tries to draw some over-dense lump together, the universe's expansion pulls it apart.

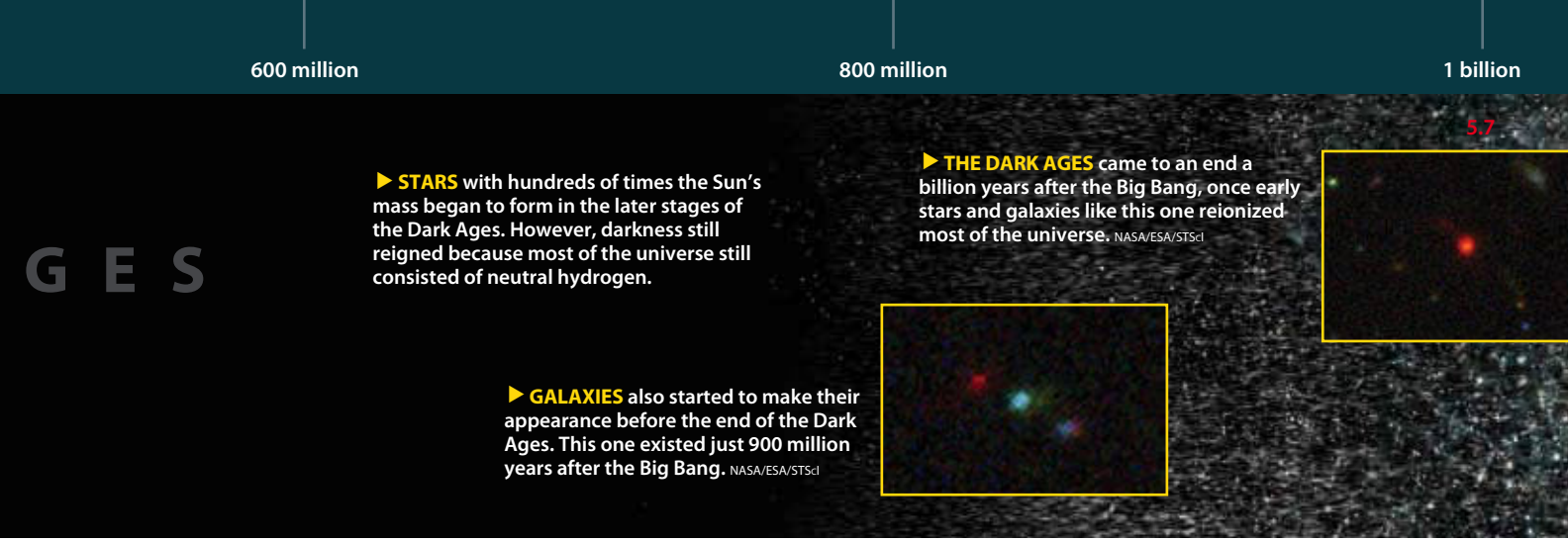
"During the earlier years of cosmological study, this struggle between gravity growing structures and expansion diluting them caused astronomers a lot of consternation," says Bryan. Originally, astronomers had hoped that any perturbation, even one as small as an atom, could grow into a cluster of galaxies. The push/pull of expansion and gravity dashed that hope.

"There needs to be a range of perturbations that already exists at recombination," explains Bryan, "and they need to be large enough to allow gravity to do its work so the structures we see now can emerge." Astronomers now understand that while the perturbations seen in the microwave



VOLKER SPRINGEL (MAX PLANCK INSTITUTE FOR ASTROPHYSICS), ET AL.

THE MILLENNIUM RUN simulation tracked 10 billion dark-matter particles to see how cosmic structure formed. This sequence shows the universe at an age of 210 million years (z = 18.3), well within the Dark Ages. Each image left to right zooms in by a factor of 4.


600 million
800 million
1 billion
5.7
▶ STARS with hundreds of times the Sun's mass began to form in the later stages of the Dark Ages. However, darkness still reigned because most of the universe still consisted of neutral hydrogen.
▶ THE DARK AGES came to an end a billion years after the Big Bang, once early stars and galaxies like this one reionized most of the universe. NASA/ESA/STScI
▶ GALAXIES also started to make their appearance before the end of the Dark Ages. This one existed just 900 million years after the Big Bang. NASA/ESA/STScI

background may be tiny, those bumps — imprinted at the Big Bang's earliest stages — are large enough to give gravity the head start it needed once the Dark Ages began.

Perturbations grew slowly as the Dark Ages progressed. Eventually, the density contrast between a growing lump and its surroundings became obvious, and gravity halted expansion in that region.

Winners and losers

When the cosmic plasma entered the Dark Ages, perturbations imprinted on it from the beginning ranged in size. Some were planet-size wiggles, and some were vast undulations that stretched across galactic distances. For many years, astronomers did not know which of these wiggles grew fastest. Did structure form from the top down, or from the bottom up?

"You must remember that most of the matter in the universe is dark matter," explains Bryan. Given dark matter's preponderance — it makes up more than 80 percent of the universe's mass — its properties determined how structure formed.

"For many years, people fought between hot-dark-matter and cold-dark-matter models," says Bryan. "Hot" and "cold" in this context mean fast and slow moving. The difference is important because fast-moving dark matter tends to stream out of any small clumps trying to grow. It's a bit like flicking marbles across a flat surface and trying to catch them in shallow depressions. If the marbles move quickly, they barely know the depressions exist. If they roll slowly, they have a better chance of getting trapped.

Hot-dark-matter models need big collections of stuff to form before gravity can make the structure collapse. With hot dark matter, the largest wiggles grew fastest. Smaller clumps formed once the big ones were done — top-down structure formation.

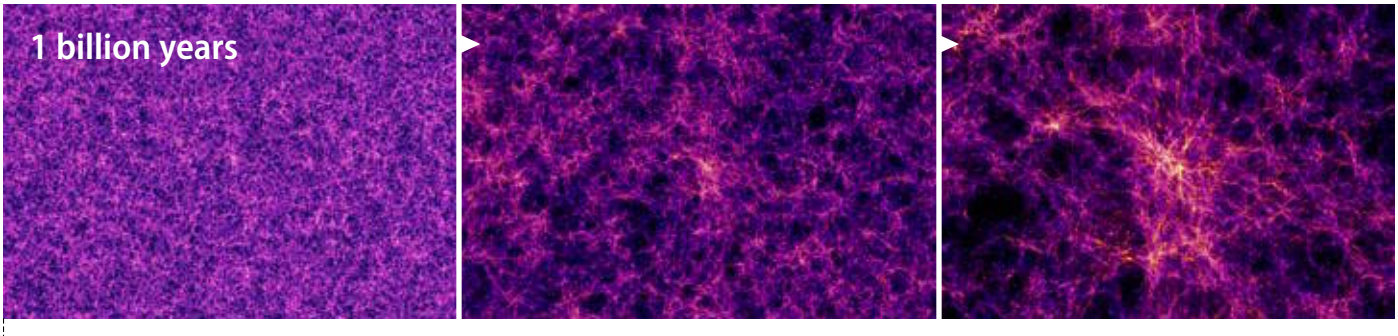
Cold dark matter does the opposite. Little wiggles grew fastest, so structure formed from the bottom up. Once the clumps collapsed, they merged with other small clumps to form ever-larger structures. By the early 1990s, astronomers had ample evidence that only cold-dark-matter models could produce the kinds of structures we see in the current universe. "The cold-dark-matter models won because they compared better with observations," says Bryan.

According to Bryan, the first objects to become gravitationally bound may have been Earth-size clumps of dark matter. But while the clump might have been about Earth's size, it would have been tenuous — at best a dark-matter ghost of a planet.

Dark clump to bright star

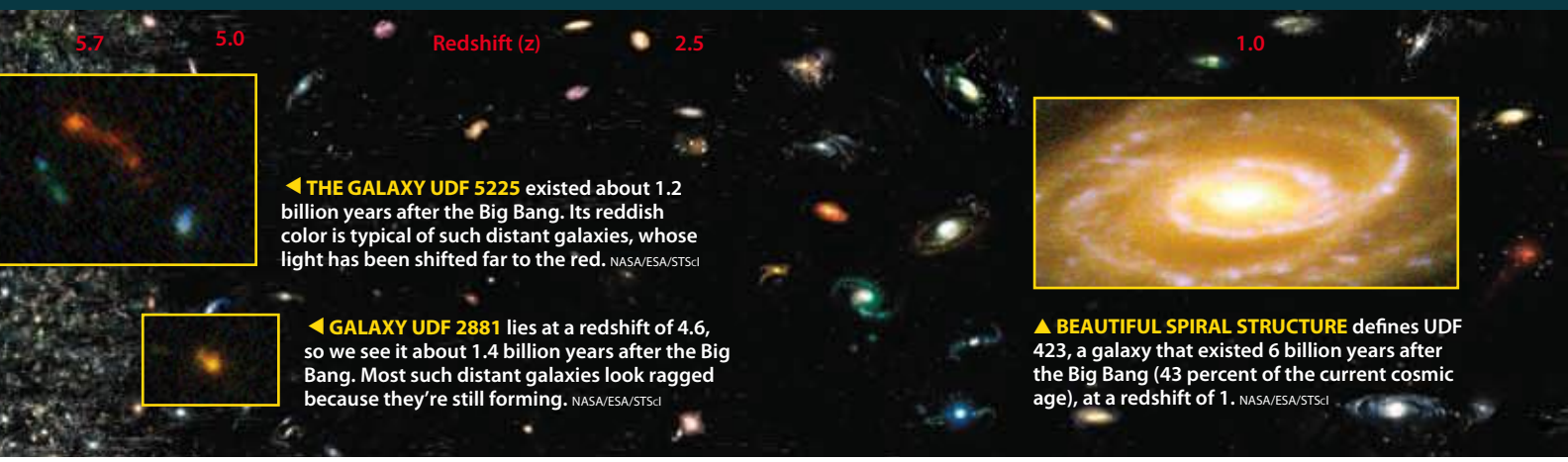
In today's universe, a giant halo of dark matter surrounds the visible part of every galaxy. Astronomers also use the term *halos* for the first dark-matter structures to form. At a redshift around z = 60, the dark-matter halos had grown to contain almost 1,000 times the Sun's mass. Ordinary matter had not yet joined the party. The 1,000 solar masses were too little to cause ordinary matter, mostly hydrogen gas, to clump. While dark matter began to form significant structures, ordinary gas was still too hot and moving too fast to be contained in the shallow gravity wells of nascent halos.

Only when the dark-matter halos grew to 10,000 times the Sun's mass could the hydrogen clump, too. The first clumping of ordinary matter — our kind of stuff — marked a critical moment in cosmic history. Unlike dark matter, normal, or "baryonic," matter can dissipate its energy. In other words, it can cool and slow down, which allowed hydrogen and helium to condense at the center of a growing dark-matter halo. This was the moment when the universe's first star was poised to form.



VOLKER SPRINGEL (MAX PLANCK INSTITUTE FOR ASTROPHYSICS), ET AL.

THE DARK AGES CONCLUDED about 1 billion years after the Big Bang (z = 5.7). At this time, the first stars — massive beasts weighing more than 100 solar masses drawn together by cold dark matter — already had formed. Galaxies had yet to form.



◀ **THE GALAXY UDF 5225** existed about 1.2 billion years after the Big Bang. Its reddish color is typical of such distant galaxies, whose light has been shifted far to the red. NASA/ESA/STScI

◀ **GALAXY UDF 2881** lies at a redshift of 4.6, so we see it about 1.4 billion years after the Big Bang. Most such distant galaxies look ragged because they're still forming. NASA/ESA/STScI

▲ **BEAUTIFUL SPIRAL STRUCTURE** defines UDF 423, a galaxy that existed 6 billion years after the Big Bang (43 percent of the current cosmic age), at a redshift of 1. NASA/ESA/STScI

To make a star, matter must collapse into the bottom of a gravitational well. The more gas that falls into the well, the higher the density. Eventually, nuclear fusion occurs, and the star turns on.

Astronomers understand how stars form in the current cosmos and know enough to paint the outline for forming the first generation of stars. Life in the Dark Ages was not that simple, however. In astronomers' quest to comprehend the births of the first stars, they have been thrown many curveballs.

"The absence of heavy elements is the most important difference between modern star formation and the creation of the first stars," explains Bryan. Astronomers call every element more massive than helium a metal. And metals are, for the most part, created inside stars. Metals in an astrophysical gas can shed heat far more efficiently than hydrogen or helium atoms. The photons emitted by metals stream out of the gas, taking energy with them. In this way, even traces of metals can act as highly effective refrigerants.

The first stars, however, formed from gas lacking metals. This primordial gas had almost no way to cool. "The cooling is very slow until hydrogen atoms combine to form hydrogen molecules," says Bryan. He also points out that molecular hydrogen in the modern universe forms on dust grains, which are made of metals. Without dust, molecular hydrogen formed so slowly that dark-matter halos grew to a million solar masses before ordinary matter could really begin to cool. "These dark-matter halos are literally microgalaxies, one-millionth the mass of a present-day galaxy, by the time the first star can begin to form," says Bryan.

THE UNIVERSE'S FIRST stars may all have been hundreds of solar masses.

The wait leads to disappointment on a cosmic scale. According to Bryan's calculations, the type of star that finally contracts from the primordial gas is a kind of monster rarely seen in the current universe.

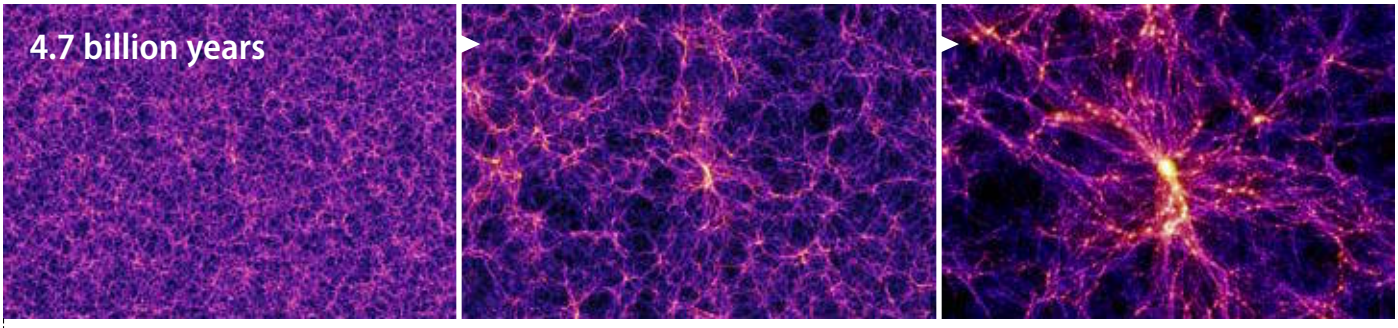
A giant's birth and death

In today's cosmos, any star larger than 8 solar masses is considered massive and has a harder time forming than its smaller cousins. Stars more than 100 times the Sun's mass are so rare that we know of only two in the entire Milky Way.

According to Bryan, the universe's first stars may all have been this big. Over the past several years, Bryan, Norman, and their collaborators have used advanced computer simulations to track the evolution of cosmic structure from the era of recombination to the formation of the first star. Unlike traditional simulation methods, Bryan's code simultaneously tracks a huge range of scales, everything from vast arcs of still-forming dark-matter halos millions of light-years across down to the outlines of the first star with a radius just a few times that of Earth's orbit.

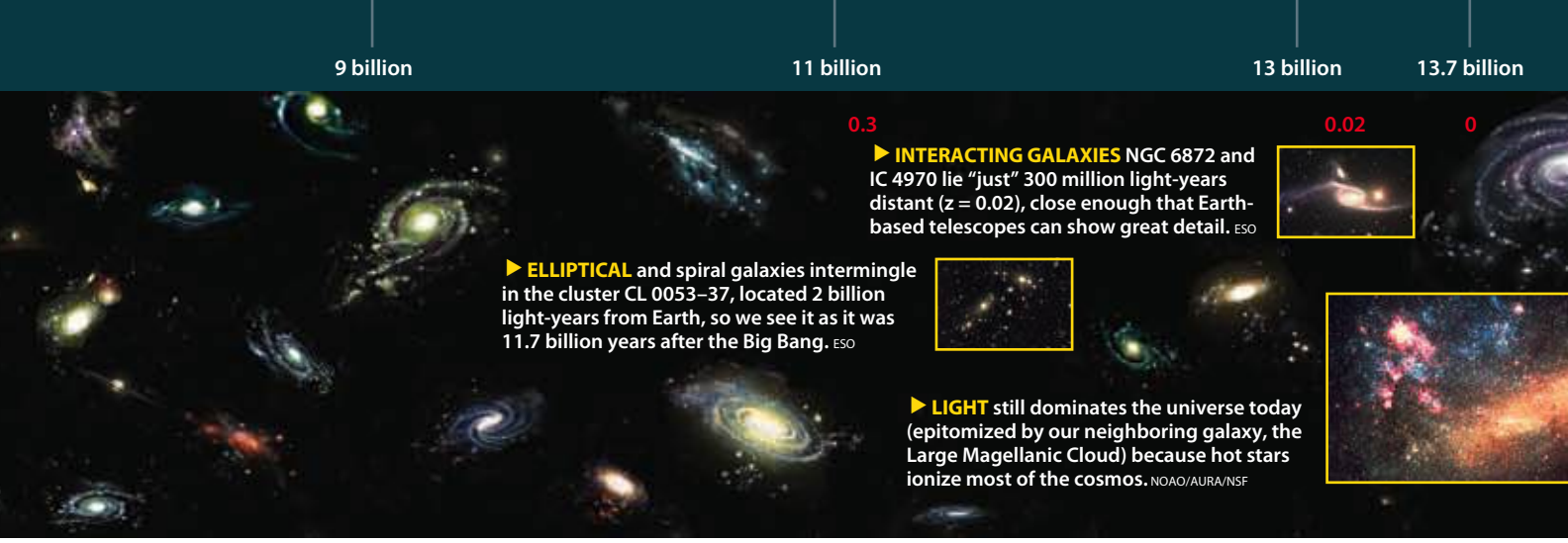
After running the codes continuously for years, the researchers found that each microgalaxy halo produces exactly one massive star. Each star weighs a few hundred solar masses. But the story doesn't end there. Massive stars burn hot and die fast. In their brief lives, they dramatically affect their environment.

The massive stars in Bryan's calculations produce a torrent of UV photons that ionize every hydrogen atom out to well beyond 1,000 light-years. "The ionization produced by the big stars heats the surrounding gas



VOLKER SPRINGEL (MAX PLANCK INSTITUTE FOR ASTROPHYSICS), ET AL.

GALAXIES AND CLUSTERS appear prominent by the time the cosmos is 4.7 billion years old (z = 1.4). On the biggest scales (left), the universe still looks fairly smooth, but closer up, individual galaxies and clusters start to dominate.


9 billion
11 billion
13 billion
13.7 billion
0.3
0.02
0
▶ INTERACTING GALAXIES NGC 6872 and IC 4970 lie "just" 300 million light-years distant (z = 0.02), close enough that Earth-based telescopes can show great detail. ESO
▶ ELLIPTICAL and spiral galaxies intermingle in the cluster CL 0053–37, located 2 billion light-years from Earth, so we see it as it was 11.7 billion years after the Big Bang. ESO
▶ LIGHT still dominates the universe today (epitomized by our neighboring galaxy, the Large Magellanic Cloud) because hot stars ionize most of the cosmos. NOAO/AURA/NSF

and, in the process, can completely unbind all the baryons from the still-forming dark-matter halo," explains Bryan. Even worse, when a star this size runs out of nuclear fuel — after only a million years — it ends its life in a titanic explosion that blows away the halo gas. Only a star bigger than 300 times the Sun's mass can escape this fate. Such hypergiant stars may implode as a black hole without ever exploding.

From darkness to darkness

Although the massive stars that form in Bryan's simulations ionize lots of gas, they don't pack enough punch to alter the balance of neutral-to-ionized hydrogen atoms completely. The universe remains dark. "We really don't know what happens next," declares Bryan. "Does the next generation of stars form in blast waves from first-generation supernovae?" Bryan and other astronomers now are focusing their efforts on the era when the Dark Ages ended — sometime between redshift 17 and approximately redshift 6.

"We know that the growing dark-matter halos create objects that probably look like today's dwarf galaxies," says Bryan. On the baryon side of the equation, successive stellar generations eventually created enough metals to bring the star-formation process in line with what we see today. At that point, stars of all masses can form.

Still, astronomers have yet to fill in the details, and many of our current ideas may be wrong. For example, no one knows what role black holes played in re-ionizing the universe. Any black hole that formed during this epoch would have drawn in gas at a prodigious rate. As the gas fell toward the black hole, it emitted ionizing UV photons.

"People used to think that re-ionization and 'first light' occurred quickly, at a redshift of around 6 or 7," says Bryan. "These days, that is not so clear." Did black-hole accretion effectively contribute to filling the universe with visible light? How did the galaxy-formation process continue to the point of building the great spirals and ellipticals we see today? Answers to these questions remain unknown.

Seeing first light

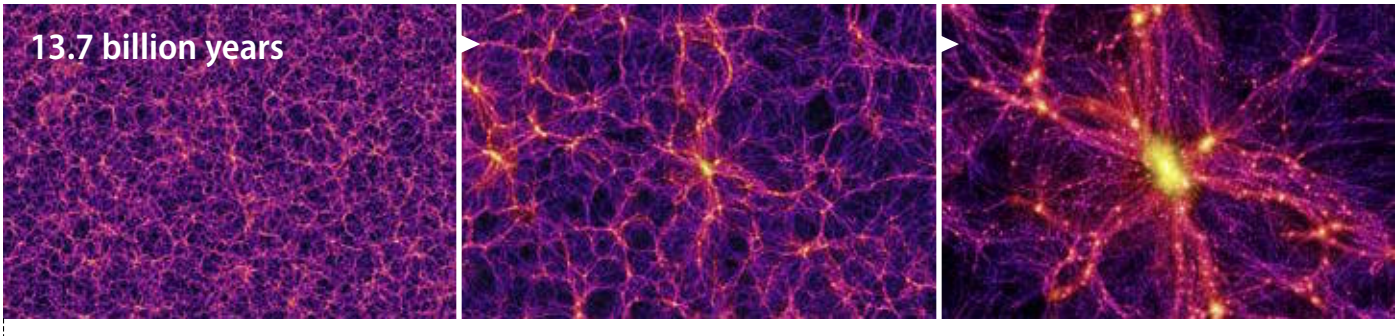
While questions concerning the first billion years abound, hope for answers does as well. An array of new instruments, scheduled to come on-line during the next decade or two, holds the promise of directly probing the Dark Ages and its end in the era of re-ionization.

The highest profile instrument will be Hubble's successor: the James Webb Space Telescope (JWST). Ultraviolet and visible light emitted during the era of re-ionization now has been redshifted to the infrared. With an 8-meter mirror and high sensitivity in the infrared, JWST will explore the nature of the objects that lit up the universe at the end of the first billion years.

In addition, astronomers hope the Square Kilometer Array (SKA) will directly probe radio waves emitted by clumps of atomic hydrogen gas during the Dark Ages. The ability to map ripples in gas density at such early times and far-flung distances could prove to be a watershed. Astronomers would get their first clear view of the early universe's initial structures.

From light to darkness to light again — this describes the unveiling of our universe's early years. By illuminating the Dark Ages, the age of first structures and massive primeval stars, astronomers are exploring a critical gap in cosmic history. With only the outlines filled and much still to be written, there can be no doubt we live in our own privileged epoch. A

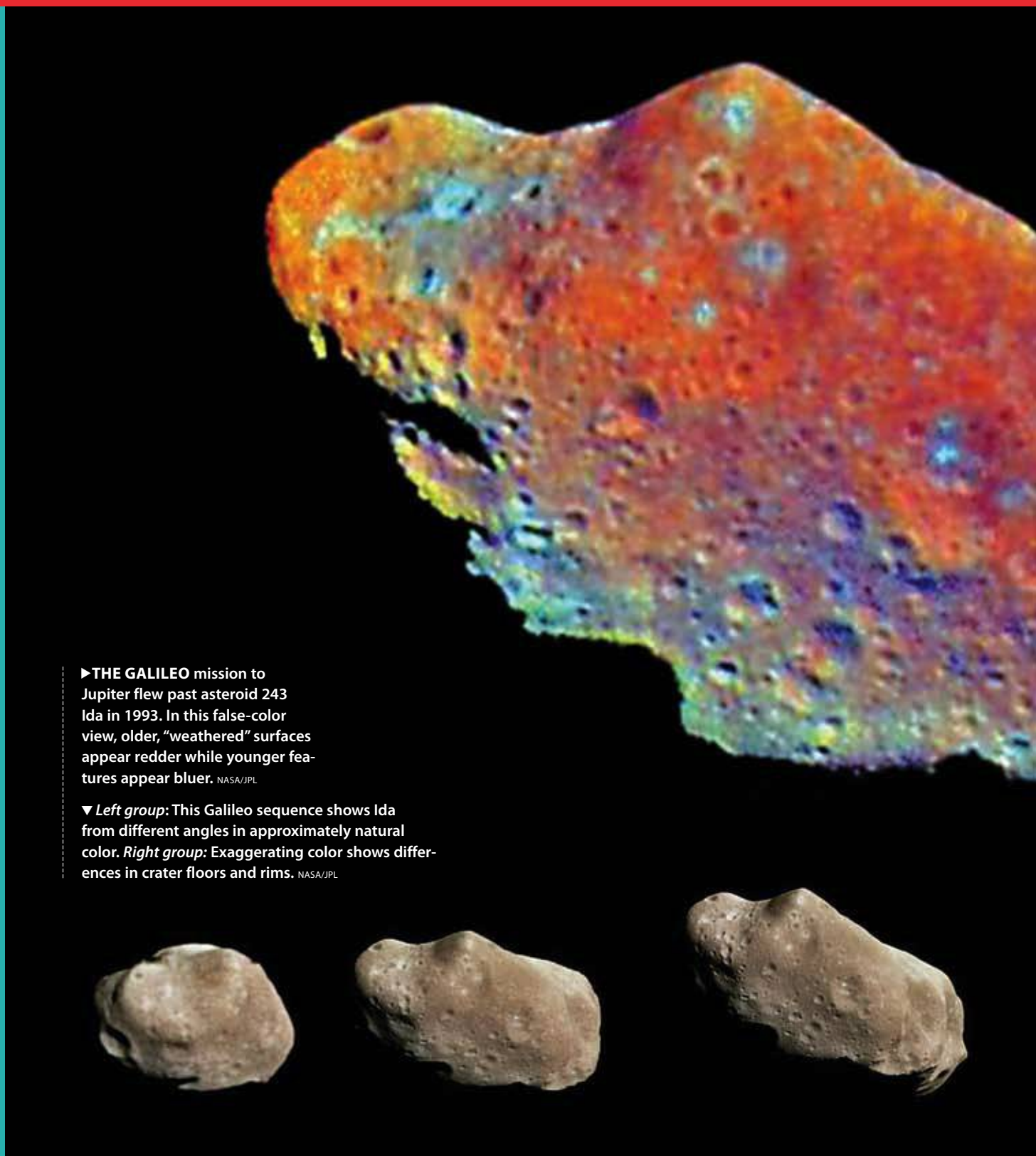
ONLINE EXTRA Learn more about plans for JWST at www.astronomy.com/toc.



VOLKER SPRINGEL (MAX PLANCK INSTITUTE FOR ASTROPHYSICS), ET AL.

IN TODAY'S UNIVERSE, rich galaxy clusters follow filaments of dark matter, with large voids separating the denser regions. Ordinary matter now pretty much follows the lead established by dark matter, and dark-matter halos surround individual galaxies.

SEEING



▶**THE GALILEO** mission to Jupiter flew past asteroid 243 Ida in 1993. In this false-color view, older, "weathered" surfaces appear redder while younger features appear bluer. NASA/JPL

▼*Left group*: This Galileo sequence shows Ida from different angles in approximately natural color. *Right group:* Exaggerating color shows differences in crater floors and rims. NASA/JPL

RED

Color is the key to understanding asteroid family histories.

/// BY PETER AND ROBERT JEDICKE

Your patio furniture has something in common with an asteroid's surface: Both show wear and tear from exposure to the elements. For a generation or more, astronomers have suspected some process of "space weathering" is the secret to understanding why asteroids appear red.

Although they still debate how the process works, scientists know the typical asteroid surface subtly changes color over millions of years. The color reveals not only the connection between meteorites on Earth and their parent asteroids, but also asteroid families descended from a larger parent body.

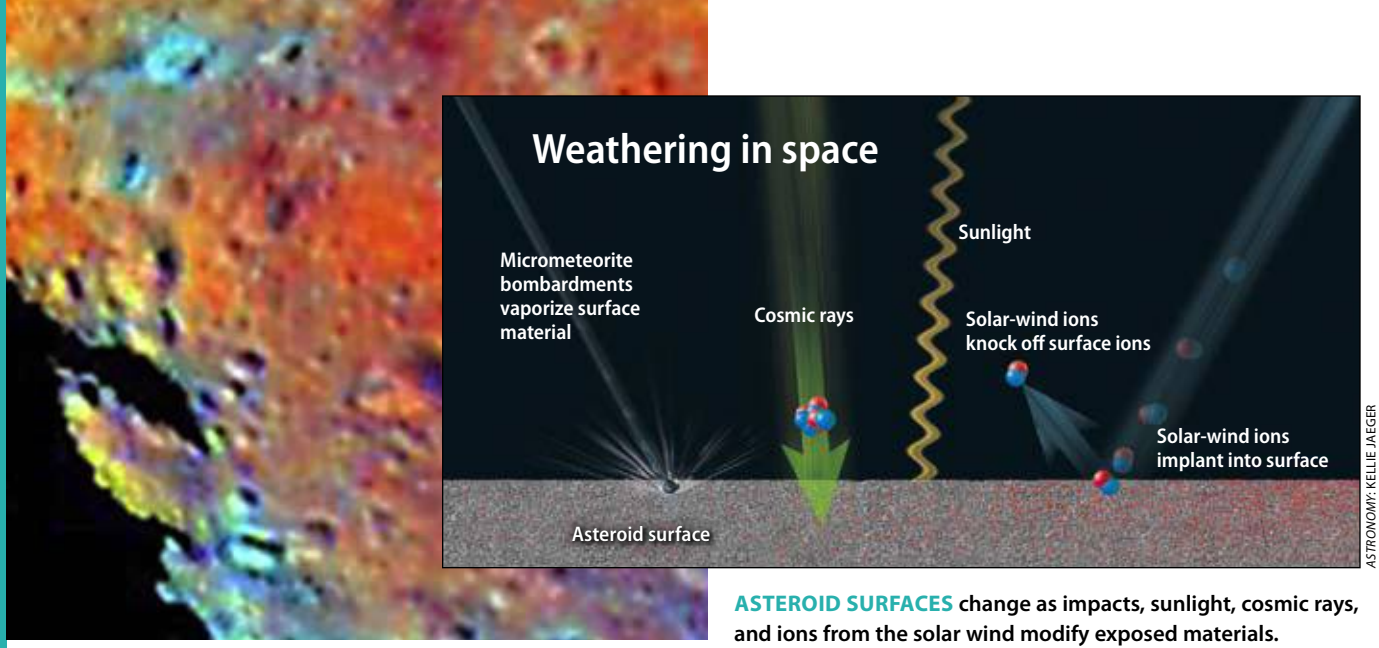
In 1929, when Nicholas Bobrovnikoff at California's Lick Observatory recorded the first spectra of minor planets, astronomers hardly knew what to expect. After all, asteroids are visible only as specks moving against the background stars. "Vermin of the sky," early astrophotographers called them.

Analysis of an asteroid's spectrum gives us an idea of the minerals present on its surface. By the 1970s, researchers like Clark Chapman of the Southwest Research Institute in Boulder, Colorado, had cast known asteroids into various classes based on what minerals appear in sunlight reflected off of them. The most populous class was given the letter "S" because its spectra indicated the presence of silicate-bearing rocks on the surface. Soon, researchers clearly identified the dominant minerals as olivine and pyroxene, both silicates.

Home for most of the S-class asteroids is the inner region of the main asteroid belt between Mars and Jupiter. In the past decade, the dizzying pace of asteroid discoveries has added tens of thousands of new bodies — some less than 0.6 mile (1 kilometer) across. In fact, astronomers now know of so many asteroids, they can apply advanced statistical techniques in studying them.

A link with falling rocks

Knowing the locations of S-class asteroids is a crucial link to the study of meteorites. Many meteorites are observed and recorded as meteors before they hit the ground, and if the



ASTEROID SURFACES change as impacts, sunlight, cosmic rays, and ions from the solar wind modify exposed materials.

camera is equipped with a timing device, astronomers can calculate the meteoroid's orbit through the solar system before it encountered Earth. It became clear that a broad category of meteorites called ordinary chondrites (OC) arrive here from the inner region of the main asteroid belt.

The obvious conclusion is that ordinary chondrite meteorites are pieces of S-class asteroids that have wandered from home and crashed to Earth. This seems even more reasonable when we look at the numbers, because S-class asteroids are the most common type, and ordinary chondrites are the most common meteorites. As a case study in the scientific method, you might consider this a classic. Just 2 centuries ago, controversy raged about whether meteorites really came from space, and, if they did, whether they were from the Moon or perhaps even the stars themselves. Now, we can link some of them to specific orbits and parent bodies.

Another line of evidence comes from meteorite spectra. The inside of a meteorite should tell us about its origins because the heat of its entry never makes it to the rock's center; when it lands, the center is still as cold as it was in outer space. In the early 1970s, researchers like Tom McCord, Mike Gaffey, and Ed Cloutis at the University of Hawaii ground up selected meteorites, ran the powdered space rocks through a laboratory spectrograph, and were able to establish connections between certain meteorites and asteroids.

For instance, there are about 500 meteorites that belong to the three categories howardite, eucrite, and diogenite (HED), and their spectra match almost perfectly with the spectrum of asteroid 4 Vesta. Museums or collectors who have examples of these three meteorite categories actually own pieces of one of the largest minor planets.

But when researchers compared spectra of OC meteorites to those of representative S-class asteroids, they saw significant differences. One is that the asteroid surfaces have a lower albedo; that is, they are darker than the meteorites.

Peter Jedicke *is a past-president of the Royal Astronomical Society of Canada. His brother,* **Robert Jedicke,** *is an astronomer at the University of Hawaii and is involved with the Pan-STARRS project.*

Also, the meteorites show absorption features at wavelengths near 1 micrometer — due to olivine and pyroxene — that are less distinct in the asteroid spectra.

Blushing asteroids

Most notably, however, the asteroids look redder. To a spectroscopist, color is not just a vague comparison with a paint chart at Home Depot but a calculation based on the strength of reflected light across a specific range of wavelengths. Although measuring the spectrum of an asteroid is complex, scientists repeatedly have confirmed the discrepancy between the outside of asteroids and the inside of meteorites. It could not be ignored. More puzzling still, the redness of S-class asteroids when compared to ordinary chondrite meteorites appears more pronounced than in comparisons of other asteroid classes and meteorites.

This problem became known as the "S-conundrum." Some scientists, led by Jeff Bell of the University of Hawaii, insisted ordinary chondrite meteorites must come from some kind of asteroid not yet seen. But no new types appeared even as the number of asteroids grew.

On the other hand, Chapman and others who favored space weathering could not explain in detail how it works. Somehow, they said, a thin layer on the surface of asteroids is turning color, and more so on some asteroids than others. What could be doing this? Bell notoriously called it "foo-foo dust" at one raucous scientific conference.

To explore possible mechanisms for space weathering, lab analysts such as Bruce Hapke of the University of Pittsburgh subjected rock powders to torture that would make lawn furniture cringe. Various materials were melted, bombarded with ions, heated by electron beams, and zapped with pulsed lasers. In each case, the key lay in what happened to iron. These hostile experiments caused atoms that were originally present as part of chemical compounds in the silicate rocks, including iron, to break free and vaporize.

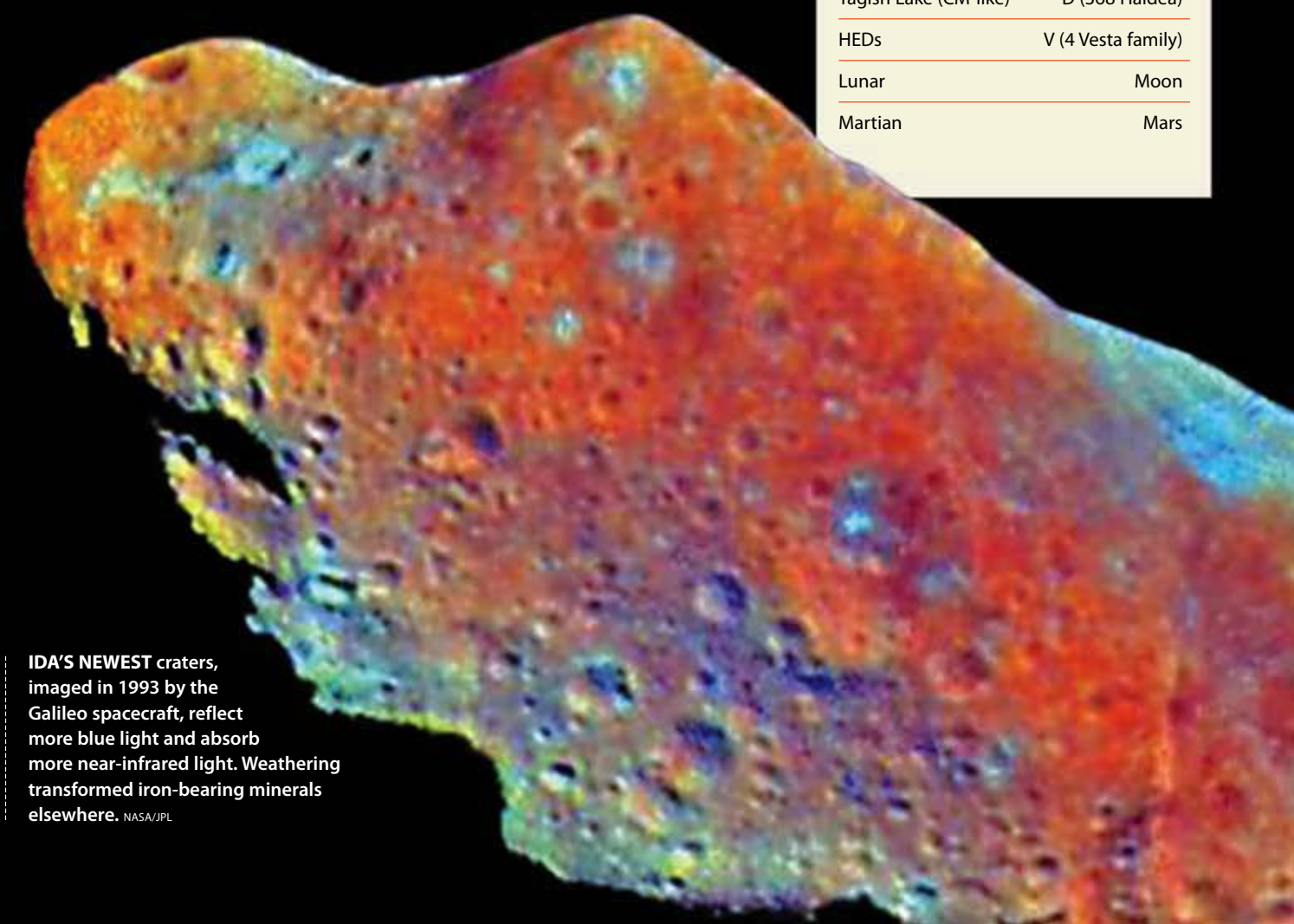
But when the iron condensed again — as it would in the cold vacuum of space — it didn't re-join the same silicate-type molecules. Instead, the iron formed metallic grains

FERMILAB VISUAL MEDIA SERVICES

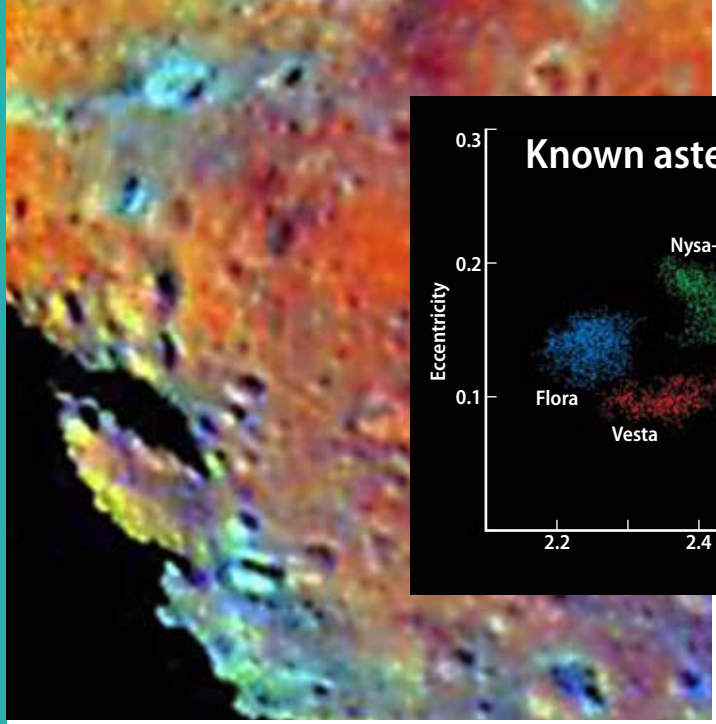
THE SLOAN Digital Sky Survey telescope (SDSS) stands out against the backdrop of the Sacramento Mountains. Designed to study galaxies, the survey picked up so much data on asteroids that astronomers could then apply powerful statistical techniques.

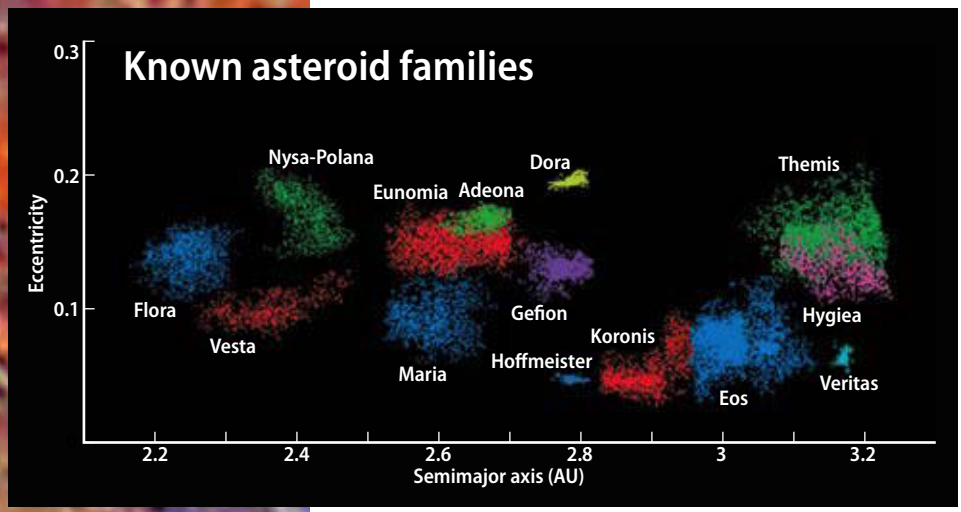
ASTEROID/METEORITE CONNECTIONS

Meteorite type	Asteroid class (family or parent body)
Iron and enstatite chondrites	M
Aubrites (enstatite achondrites)	E (3103 Eger)
Ordinary chondrites (L, LL)	S(IV)/Q
Ordinary chondrites (H)	S(IV) (6 Hebe)
Ureilites, acapulcoites, angrites	S
Iodranites, winonaites, pallasites, brachinites	A
R	A or S
CI, CR, CK	C
CH	C or M
CM	C, G, Ch
CV, CO	K (221 Eos family)
Tagish Lake (CM-like)	D (368 Haidea)
HEDs	V (4 Vesta family)
Lunar	Moon
Martian	Mars



IDA'S NEWEST craters, imaged in 1993 by the Galileo spacecraft, reflect more blue light and absorb more near-infrared light. Weathering transformed iron-bearing minerals elsewhere. NASA/JPL





ASTRONOMY: ROEN KELLY, AFTER M. JURIĆ, Ž. IVEZIĆ, R. LUPTON ET AL., 2002

ASTEROID FAMILIES emerge when astronomers plot an asteroid's color against orbital parameters such as size and eccentricity. Each dot represents an asteroid, which is plotted with approximate color. The clusters reveal asteroid families.

about 1/10,000 of a millimeter in diameter, called submicroscopic metallic iron (SMFe). The grains are so tiny that when Hapke suggested this process in 1975, the grains could not be detected in the outer surface of rocks brought back from the Moon. It wasn't until scientists scanned lunar soil particles with a transmission electron microscope that they saw SMFe clearly embedded in their surfaces.

Iron is famous for adding hints of red in various ways. On the Moon, the iron would be darker and it would mask the olivine/pyroxene spectral band. But astronomers worried space-weathering processes on the Moon might act differently from those in the asteroid belt. Sunlight on the Moon is about 5 times as intense as in the asteroid belt. And micrometeoroid particles hitting the Moon are moving faster on average than those that hit main-belt asteroids. Either way, there's less available energy to vaporize iron in silicate compounds on asteroids than on the Moon.

In 2000, Hapke showed OC meteorites need 1/20 the amount of iron as Moon rocks to alter their appearance. Thus, even though there's less available energy in the asteroid belt, explaining the appearance of S-class asteroids also requires less submicroscopic iron. Researchers are approaching a consensus that the dominant process there is, indeed, micrometeoroid impacts. The effect depends on the amount of iron in the original surface material. This explains why some asteroid types turn redder than others.

Constant gardening

Asteroids experience all manner of impacts: catastrophic ones big enough to break huge chunks off asteroids, and modest strikes that would just mix up the surface. Collectively, astronomers refer to these surface effects as "gardening" the asteroid. Like sanding off weather-beaten layers on patio furniture, gardening may help asteroids stave off space's weathering effects. Richard Binzel at the Massachusetts Institute of Technology and his colleagues have calculated that Vesta — which shows little reddening in comparison to its associated HED meteorites — recently may have been "resurfaced."

In 1997, astronomers using the Hubble Space Telescope detected a 285-mile-wide (460 kilometer) impact crater on Vesta. The asteroid itself is only 330 miles (530 km) wide. The HED meteorites are basalt lava erupted from the interior of Vesta's much larger parent body.

ASTRONOMERS ARE CERTAIN each family consists of fragments of a once-larger asteroid that broke up.

Spacecraft have visited four S-type asteroids: 951 Gaspra, 243 Ida, 433 Eros, and 25143 Itokawa. Instruments on the Galileo and NEAR Shoemaker spacecraft sent back detailed photographs and data that Chapman, Joseph Veverka of Cornell University, and others analyzed to look for the reddening effect. Indeed, younger features like craters or crater ejecta are less red, and regions astronomers think are older are more red.

Family ties

Astronomers also group asteroids by their orbits. In 1918, Japanese astronomer Kiyotsugu Hirayama noticed that almost 10 percent of the 790 asteroid orbits then known fit into three remarkably distinct families. Members share orbital characteristics, such as orbital inclination and eccentricity. More and more families were identified, and by the 1990s, dozens of groups were known.

Each group is named by its lowest-numbered member. Two of Hirayama's discoveries, the 221 Eos and 158 Koronis families, are among the largest, with hundreds of members.

Chance could not have brought these families together: Astronomers are certain each family consists of fragments of a once-larger asteroid that broke up.

The newest research on asteroid families comes from David Nesvorny of the Southwest Research Institute. Using orbital parameters that don't change over time, Nesvorny and his coworkers have calculated the age for about 40 families; that is, the time since the parent body broke apart. That's when the interior of the parent body was first exposed to space weathering. Spectra of family members do, indeed, show the same degree of reddening, particularly for the dozen S-class families. By measuring the reddening for a variety of families and comparing it to their ages, astronomers have finally determined the pace of change on an asteroid's surface.

Meanwhile, more data became available from the Sloan Digital Sky Survey (SDSS). This highly automated 3.5-meter telescope, located at Apache Point Observatory in New Mexico, was designed to observe distant galaxies, not nearby asteroids, but SDSS can't help netting asteroids by the digital truckload. The system's software identifies moving objects and compiles them in a database. Over 125,000 objects have been cataloged; 8,400 of them have been identified as asteroids that belong to recognized families. And because SDSS measures light in five specific wavelengths, the data are a treasure trove for color analysis.

The data show the oldest S-class families are those of 15 Eunomia and 158 Koronis, each about 2.5 billion years old. They're also the reddest. If a typical OC meteorite were left in the asteroid belt that long, space weathering would make the meteorite's surface look like those reddened asteroids.

But members of the 832 Karin family broke apart a mere 5.8 million years ago, and their colors are much more like fresh ordinary chondrite meteorites. Now that astronomers know how slowly space weathering takes place, and that submicroscopic iron is the cause of the reddening effect, this is almost a complete solution to the S-conundrum.

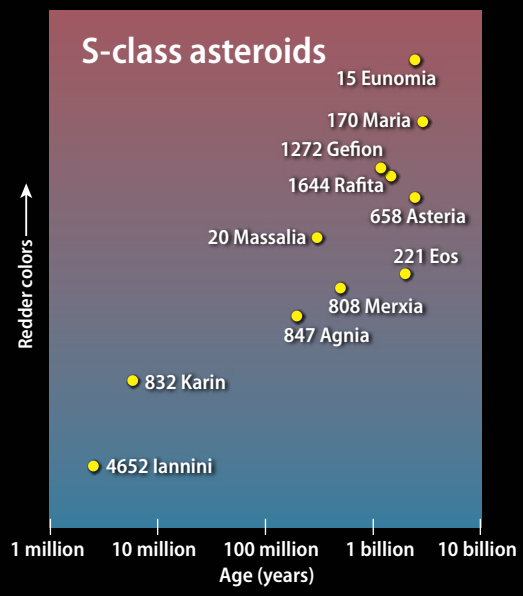
Remaining problems

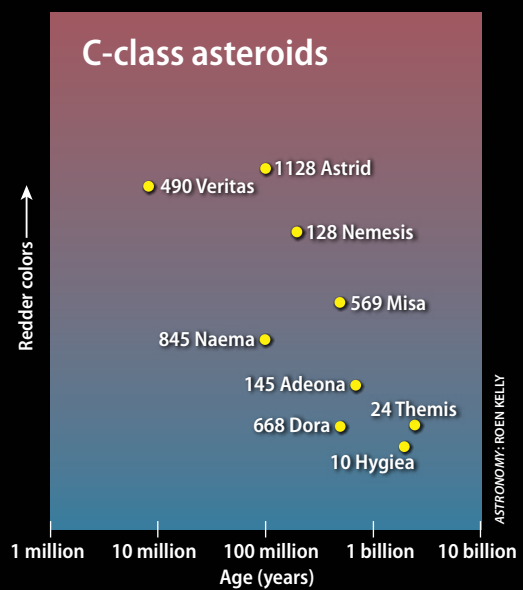
Not everything is squared away, however. SDSS data come from five color filters instead of a spectrograph that scans wavelengths, and this makes it difficult to discern fine distinctions across spectra. Also, SDSS has revealed a new riddle: C-class asteroid families grow *less* red with age. C-class asteroids are thought to be related to carbonaceous chondrite meteorites, which contain much less silicate-bearing rock. This result took asteroid experts by surprise.

Bolstered by this new scientific consensus, researchers will continue to develop the details of how space weathering takes place. If it turns out that the material in S-class asteroids is similar to that which formed the inner planets, understanding space weathering will be all the more important.

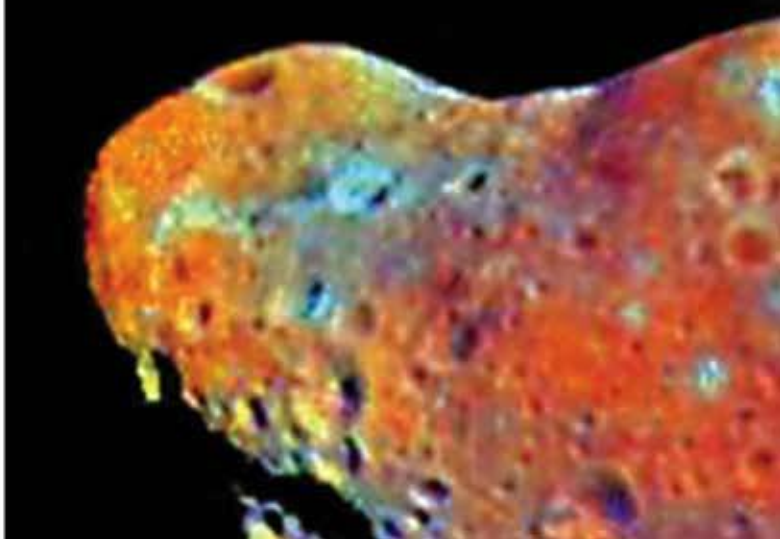
Japan's 2005 Hayabusa probe flown to asteroid Itokawa is just one mission that has helped establish the technology needed to return asteroid samples to Earth. One way or another, rock from beneath an asteroid's surface someday will be brought together with a laboratory spectrograph on Earth. We may not have a secure scientific answer about how space weathering works until then.

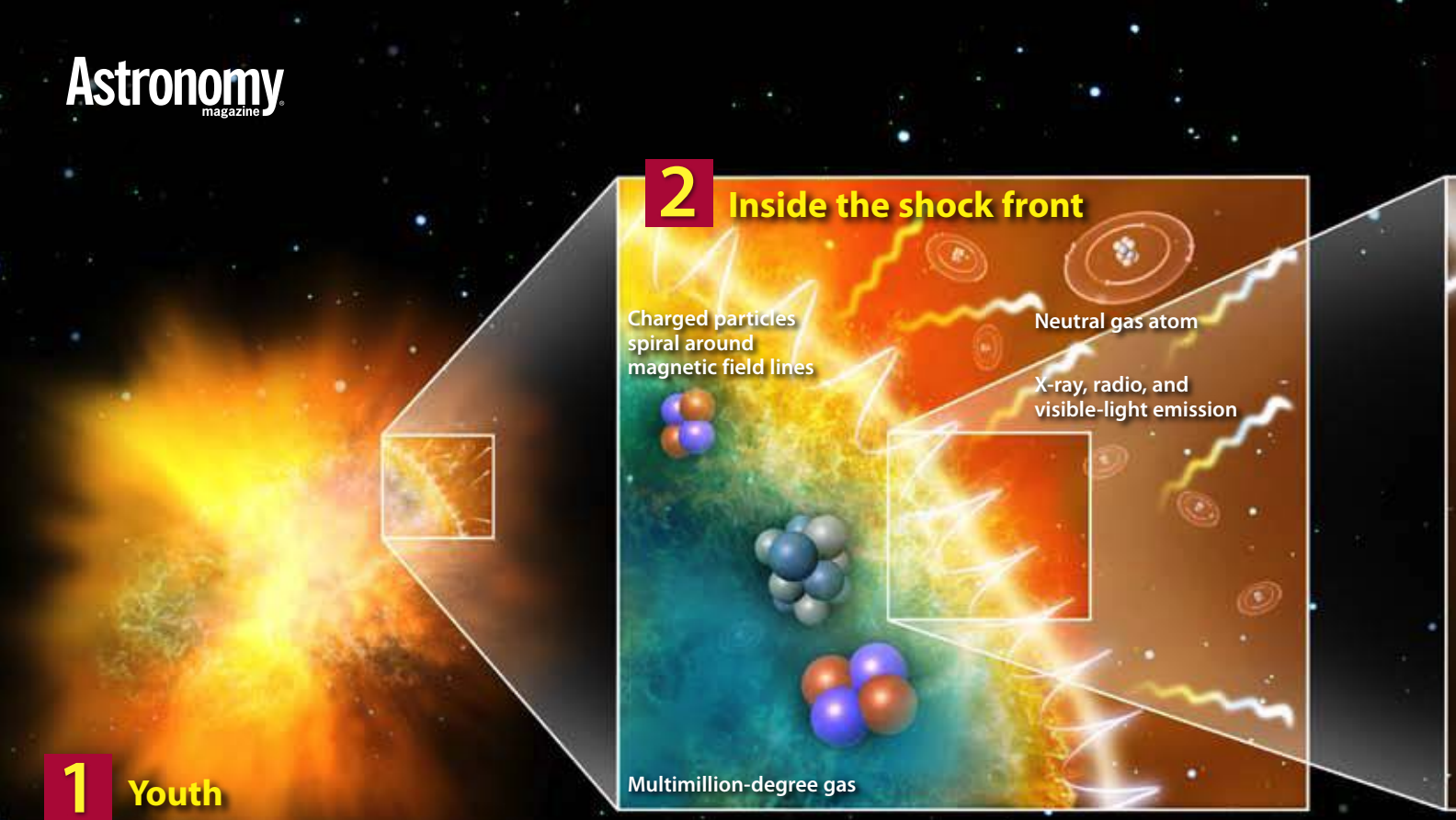
Unsolved mystery





THE BLUSH of age shows up clearly in this plot of S-class asteroids (top). But scientists can't yet explain why C-class asteroids (bottom) trend the other way.




2 Inside the shock front
Charged particles spiral around magnetic field lines
Neutral gas atom
X-ray, radio, and visible-light emission
Multimillion-degree gas

1 Youth

A few centuries after the explosion, a supernova's remnant may span 15 light-years. X rays stream from the interior's super-hot gas. The remnant's edge emits radio waves, and dust glows in the infrared. Only a few filaments emit visible light. The remnant of Kepler's supernova is in this state today.

4 Adolescence

Over the next 20,000 years, the shell expands to about 100 light-years. During this time, interstellar matter "snowplowed" by the shock front mixes with hot stellar debris, which amplifies the remnant's magnetic field.

5 Maturity

After about 20,000 years, the remnant's hottest gas has cooled to less than a million degrees. Electrons recombine with ionized atoms, which then emit visible light. This process illuminates the remnant, which radiates most of its energy as visible light. It also accelerates how fast the gas cools and slows the remnant's expansion.

Supernova aftermath

A supernova's impact lives on long beyond its fading light.

/// BY FRANCIS REDDY

ILLUSTRATION BY DANA BERRY

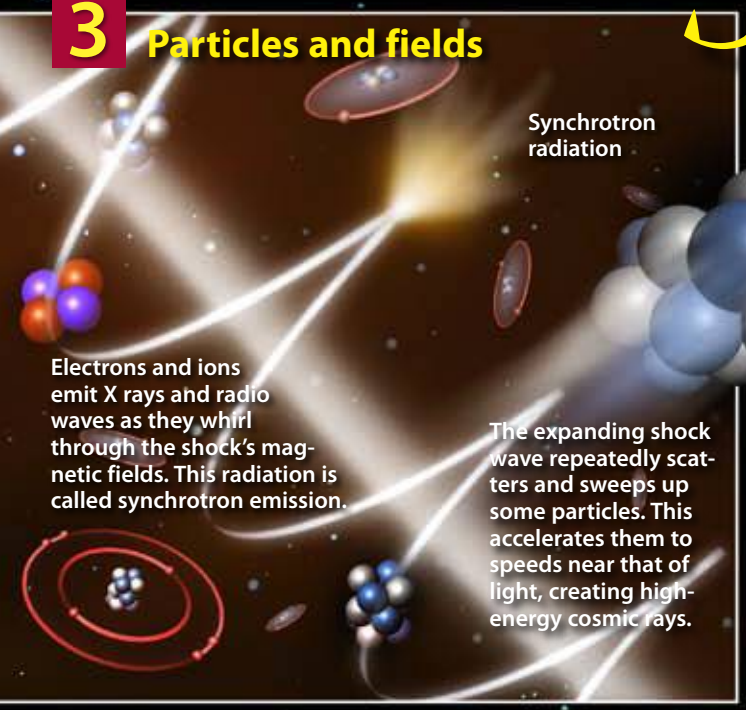
The Milky Way is overdue for a supernova. Astronomers say a star should detonate in our galaxy every 50 years or so. Johannes Kepler saw our galaxy's last visual supernova in 1604, six years before the telescope's invention.

For planets and people, what happens after the blast is a supernova's most important aspect. The explosion liberates carbon, oxygen, iron, and other elements forged in a massive star's heart. Scattered back into space, these elements enrich the interstellar medium for later generations of stars — and the planets that may form near them. It's the ultimate in recycling.

The explosion may completely destroy the star, or its core may live on as a superdense, city-size neutron star — or even a black hole. The star itself initially expands at more than 10 million mph (16 million km/h) and transforms into an X-ray- and radio-emitting sea of electrons, protons, and nuclei tangled in magnetic fields.

The supernova remnant evolves quickly. It sweeps up gas and dust the star shed before it blew up. This expanding plasma continues to affect interstellar space for millions of years.

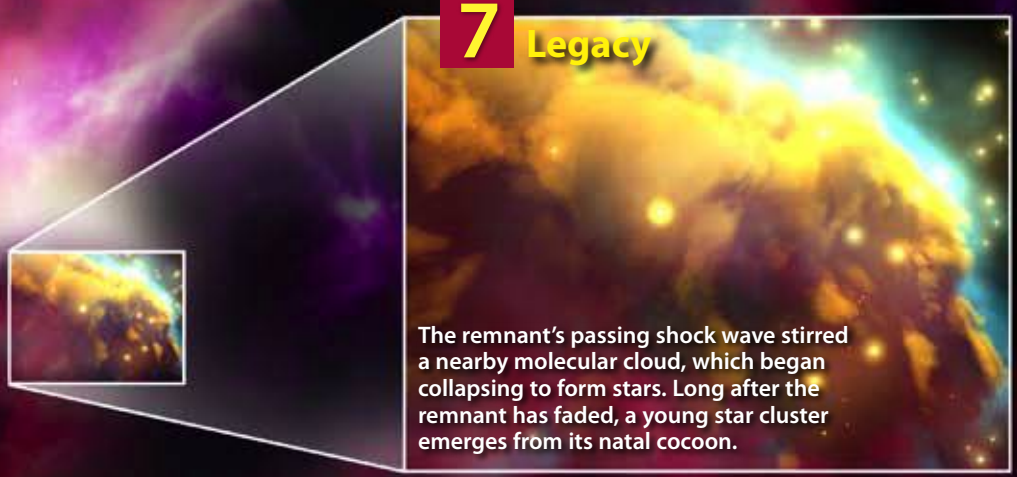
3 Particles and fields


Synchrotron radiation
Electrons and ions emit X rays and radio waves as they whirl through the shock's magnetic fields. This radiation is called synchrotron emission.
The expanding shock wave repeatedly scatters and sweeps up some particles. This accelerates them to speeds near that of light, creating high-energy cosmic rays.
Accelerated cosmic ray

6 Decline

Millions of years after the blast, the remnant may span more than 1,000 light-years. Instabilities begin breaking up its shell, which mixes with the interstellar medium.

7 Legacy



The remnant's passing shock wave stirred a nearby molecular cloud, which began collapsing to form stars. Long after the remnant has faded, a young star cluster emerges from its natal cocoon.

{ EXCLUSIVE }

How we discovered Pluto's new

Planetary scientists S. ALAN STERN and HAL WEAVER take us inside the search for new worlds.

Since Charon's discovery in 1978, the world had viewed distant planet Pluto as the "Pluto-Charon binary." Now, with our team's discovery last year of Pluto's two small moons, we know Pluto is a far richer, quadruple system. Here's the story of how our team made this discovery, what it tells us about the nature of the Pluto-Charon system, and how the newly discovered moons relate to Kuiper Belt objects in general.

Planetary scientists **S. Alan Stern** *and* **Hal Weaver** *are the principal investigator and project scientist, respectively, of NASA's New Horizons mission to Pluto.*

Persistence, pluck, and luck

Our efforts to determine whether Pluto has satellites other than Charon began in January 1988, when one of us (Alan Stern) gave a talk on this possibility at the American Astronomical Society's winter meeting in Austin, Texas. His idea was simple: Charon orbits deep in Pluto's gravitational well, just 1 percent of the way from Pluto to the 1.25-million-mile (2 million kilometers) distant borderline where the Sun's gravitational pull would strip satellites away. Given all that volume within which small moons could orbit, and no deep searches to rule them out, why not have a look? After all, the discovery of additional moons could be used to refine the masses of Pluto and Charon and shed light on the creation of the Pluto-Charon pair.

Based on this, Alan and colleagues surveyed Pluto using the 2.1-meter reflector at McDonald Observatory in 1987 and 1988 and the Michigan-Dartmouth-MIT 2.4m reflector on Kitt Peak in 1990. They also analyzed Hubble Space Telescope (HST) images taken in 1991 and 1994. These data ruled out satellites brighter than about 22nd magnitude and, therefore, larger than about 60 miles (100 km) wide, far from Pluto. The data also ruled out moons larger than about 185 miles (300 km) in diameter in regions tougher-to-observe near Pluto

PLUTO'S SYSTEM comprises four worlds. Looking out from one of the small, newly discovered moons — P1 — you can see the largest moon Charon to the left and distant Pluto and P2 in the upper right. Astronomers believe the two small moons were created in the same collision that created Charon.

LYNETTE COOK FOR *ASTRONOMY*

worlds

and Charon, where their glare presents a challenge to satellite detection.

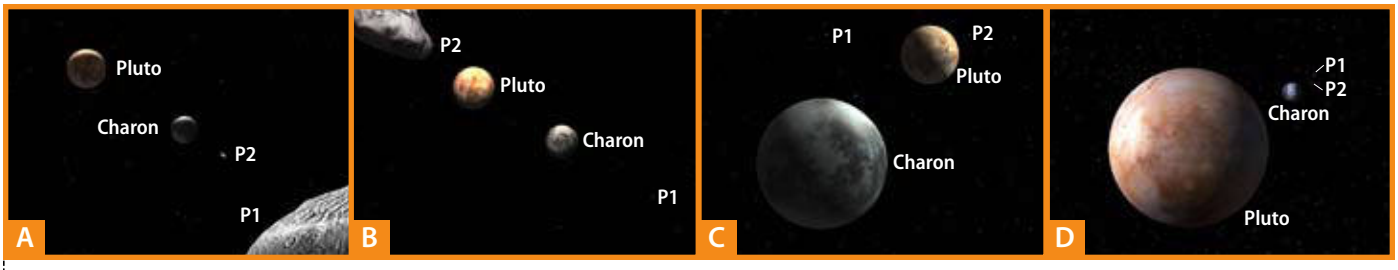
Although these searches narrowed the possible sizes of any potential Pluto moons, they were still nowhere near the size limit of the outer solar system's smallest moons that had been discovered from Earth. Any search for objects this small would have to go even deeper.

With the development of the New Horizons mission to Pluto underway in the early part of this decade, we had additional motivation for renewed searches: The discovery of other plutonian satellites would allow us to plan detailed observations of them using New Horizons.

Early in 2003, Alan and New Horizons project scientist Hal Weaver discussed a strategy for performing a search for Pluto's possible moons using HST. We realized observations using the newly commissioned Advanced Camera for Surveys (ACS) would far surpass anything done previously. So Alan, the New Horizons mission principal investigator, asked science-team member John Spencer to lead a special Hubble Director's Discretionary Time proposal to make observations in support of New Horizons during Pluto's next opposition in late spring 2003. By then, Pluto would move even closer to the galactic plane, where numerous background stars would complicate a search for faint companions.

Spencer's proposal was turned down. Disappointed, but undaunted, we proposed again in early 2004. This time, Hal led the HST proposal, but again it was rejected.

Sometimes, one group's misfortune is another's windfall. In August 2004, the Space Telescope Imaging Spectrograph (STIS) aboard HST experienced a fatal malfunction, preventing its further use. To fill the observing-time gap left by STIS proposals that could no longer be executed, the HST project promoted a slew of recently failed proposals that had been ranked just below the cutoff. Lo and behold, our Pluto



ASTRONOMY: FRANCIS REDDY

THE VIEW from objects in the Pluto system is striking. Each view includes all four members of the quadruple system, where A shows P1 in the foreground; in B, P2 is in the upper left; C shows Charon in the foreground; and in D, Pluto takes center stage.

satellite search was one of these! We got the good news by e-mail in September 2004: We had received two orbits of HST time.

The snare

Our HST search was scheduled for spring 2005, about a month prior to Pluto's opposition. We obtained ACS images of the Pluto field on May 15 and 18. We took five images during a single orbit on each date. An initial half-second exposure captured Pluto and Charon without saturation, and we followed with four 8-minute exposures to bring out any faint companions. By obtaining multiple images on each date, we could identify and reject cosmic-ray strikes that might mimic Pluto satellites in the images.

We knew these observations would be able to detect faint 27th-magnitude objects in most portions of the images. This is approximately 100,000 times fainter than Pluto and about half a billion times fainter than the human eye can see. If Pluto had any moons, even as small as 6 miles (10 km) across, HST would likely find them.

Observations on May 15 and 18 went without a hitch. We received each observation's data within a day, but New Horizons was in the thick of testing, so the first careful examination of the data didn't occur until June 15, 2005. This was when Space Telescope Science Institute (STScI) astronomer Max Mutchler — an ACS expert Hal brought in to assist with data analysis — spotted two faint satellite candidates. The objects Mutchler found appeared between 2 and 3 times as far from Pluto as Charon, and they seemed to be moving around Pluto in the same direction as Charon. However, Weaver and Mutchler kept the news to themselves: They were both busy analyzing Deep Impact observations.

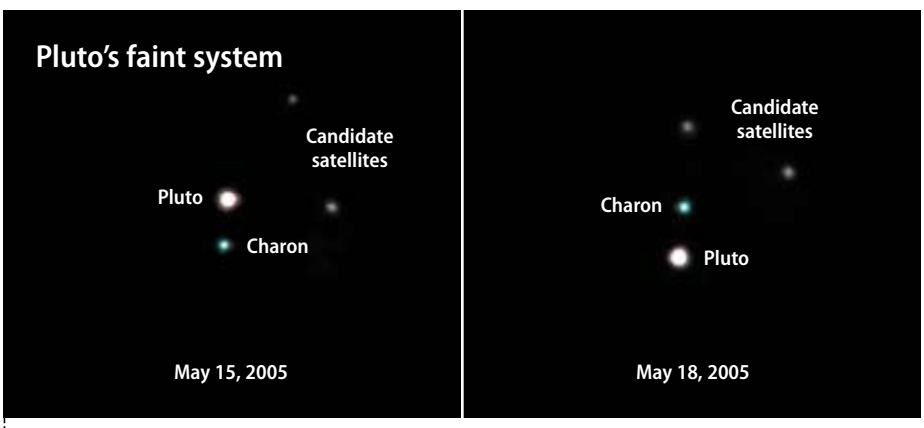
In mid-July, Alan Stern asked Southwest Research Institute (SwRI) astronomer and spectroscopist Andrew Steffl to review the HST images. On August 18, Steffl reported finding two faint satellites, each roughly 23rd magnitude, orbiting Pluto. Stern and Steffl became convinced the two candidate satellites were real, rather than image artifacts, foreground asteroids, or background Kuiper Belt objects (KBOs).

On August 24, Stern contacted Weaver about Steffl's apparent detections. To Stern's amazement, Weaver told him that he and Mutchler had also found the two satellites in June. When the brightnesses and positions of the Weaver-Mutchler and Stern-Steffl candidates were compared later that afternoon, it became clear both groups had found the same objects in the same images.

At this point, we embarked on two parallel paths: to scrutinize the HST data to ensure no camera artifacts such as optical ghosts or bad pixels were fooling us, and to seek confirming images. The announcement of new moons orbiting Pluto was sure to be a high-profile event, so it was crucial to be positive the candidate satellites were real.

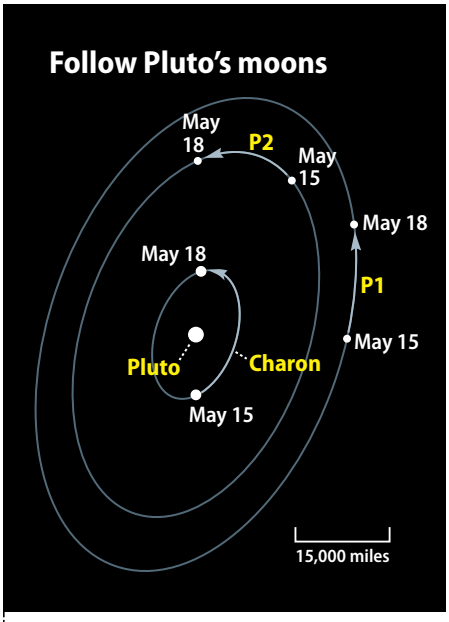
Re-observing the Pluto system with HST wasn't an option because Pluto was in a part of the sky that couldn't be observed again until February. Instead, we attempted to confirm the satellites with the help of SwRI's Bill Merline, in September and October, using the Keck and Gemini telescopes in Hawaii, and the ESO-VLT telescope in Chile. Unfortunately, these attempts did not detect the satellite candidates. Pluto was barely visible before setting each September night just after twilight.

We finally confirmed our findings in two steps. First, Merline brilliantly demonstrated that the candidate moons appeared to be moving in orbits in the same plane as Charon, and with low orbital eccentricity — also like Charon. Although we couldn't prove this with just two image sets, the HST data fit the hypothesis. Second, this made it possible to direct our collaborators, Marc Buie of Lowell Observatory and Eliot Young, also of SwRI, where to look in shorter-exposure HST images they had taken of Pluto-Charon in 2002. Then, knowing roughly where to look and what brightness to expect, Buie and Young found



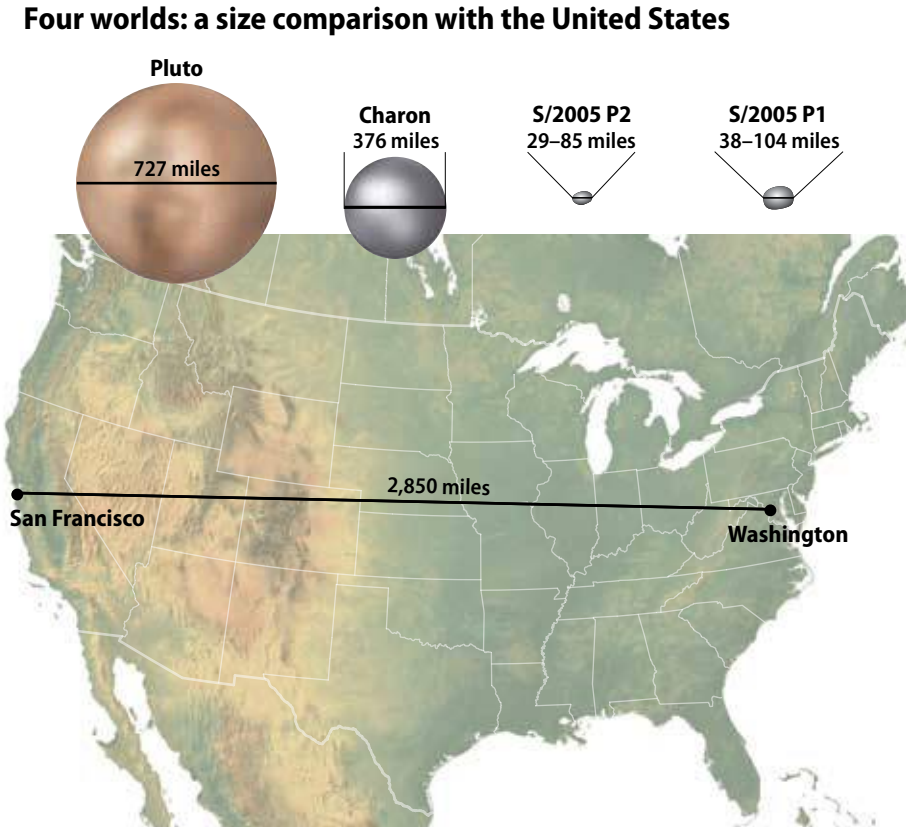
NASA/ESA/H. WEAVER (JHU/APL)/A. STERN (SwRI)/HUBBLE SPACE TELESCOPE PLUTO COMPANION SEARCH TEAM

HUBBLE'S SHARP VISION captured Pluto's small new worlds. Astronomers took multiple 8-minute images to bring out the moons' faint light.



ASTRONOMY: ROEN KELLY AFTER NASA/ESA/W. J. MERLINE (SwRI)/PLUTO COMPANION SEARCH TEAM

PLUTO'S NEW MOONS orbit the planet in the same plane as Charon. The locations of Charon, P1, and P2 on the days HST imaged them are marked.



EACH MEMBER of the Pluto quadruple system is smaller than the United States. While the distance between San Francisco and Washington is roughly 2,850 miles (4,590 kilometers), Pluto is about one-quarter this size with a diameter of 727 miles (1,170 km). P1 and P2 are tiny in comparison — possibly as small as 29 miles (46 km) across. The four objects of the quadruple system are shown in the order of their orbits out from Pluto. ASTRONOMY: ROEN KELLY

the two candidate moons within days. The moons were just barely above the archival images' noise level. Pluto was, indeed, a quadruple system!

With our findings confirmed, public announcement came a week later, on October 31, 2005. STScI sent out a press release, and the International Astronomical Union (IAU) issued an official *Circular* notice communicating the technical details.

P1 and P2; P3 and P4?

The IAU gave Pluto's two new satellites provisional designations of S/2005 P1 and S/2005 P2. Now that we have taken confirming observations February 15 and March 2, 2006, we will assign more poetic names — subject to IAU approval. From the 2002 and 2005 HST images, we confirmed that the new, outer moons of Pluto follow nearly circular orbits in the same plane as Charon. Satellite "P1" orbits about 40,000 miles (64,700 km) from Pluto, taking about 38 days to complete each circuit. Satellite "P2" orbits about 31,000 miles (49,400 km) from Pluto, taking about 25 days.

We don't know how reflective the moons' surfaces are, but we can estimate their sizes based only on the range of possible reflectivities. P1 is likely between 38 miles (61 km) and 104 miles (167 km) wide, and P2 is perhaps 29 miles (46 km) to 85 miles (137 km) across. Clearly, Pluto's outer moons are tiny compared to Charon, which itself sports a diameter of just over 376 miles (605 km).

When we, together with our colleagues, took the March 2 HST data, we used two different filters to analyze the moons' colors. With this data, we found P1 and P2 are neutrally colored, like Charon. The gray color of the Pluto-system satellites suggests all three moons were created in the same collision, although more observations are needed to confirm this theory.

As many as three observing teams, including our own, submitted HST proposals to measure the light curves, colors, and other properties of Pluto's still nameless, outer moons. Meanwhile, theorists are writing papers about the origin of this system.

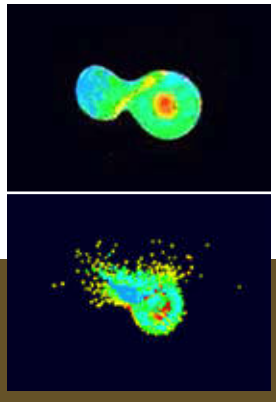
When we embarked on this effort, we knew we'd be fortunate to find Pluto and Charon had a companion. Finding two moons was doubly special! Finding them relatively near Charon was a pleasant, unexpected surprise.

The new moons' positions in Charon's orbital plane also suggest they may have formed in the same giant collision between a former KBO and Pluto that is thought to have formed Charon.

But why should such an event create such small leftovers, and only two? Might there be other, still smaller moons lurking in the Pluto system? It's possible. And might other binaries orbiting in the Kuiper Belt also have more moons? We suspect that as well, and we aim to find out.

ONLINE EXTRA Pluto may have a ring system. Visit www.astronomy.com/toc to find out more.

Are Pluto and Earth two of a kind?



Pluto's three satellites, like Earth's Moon, may have formed from a giant collision. /// BY RAY VILLARD

Astronomers have debated Pluto's planetary status for more than a decade, but the recent discovery of two new moons orbiting the distant ice world makes its identity crisis more acute. When the first moon, Charon, was discovered in 1978, only planets were known to have moons, and possession of a moon seemed to raise Pluto's declining status.

We now know that satellites around asteroids and Kuiper Belt objects (KBOs) occur frequently. So, the presence of new satellites doesn't solidify Pluto's standing as a planet. But they add surprising complexity to the system; complexity that parallels the birth of Earth's Moon.

Similarities between the Earth and Pluto systems often are overlooked in the Pluto planethood debate. However, astronomers have long understood Earth and Pluto share a unique kinship — they're the solar system's most obvious examples of binary planets. Earth and Pluto are the only two planets with moons a substantial fraction of their own diameters.

Ray Villard *is the news director for the Space Telescope Science Institute in Baltimore and is a frequent* Astronomy *contributor.*

Double planets

Our Moon has 1/80 of Earth's mass, and Pluto's largest companion, Charon, is about 1/10 of Pluto's mass. In contrast, the largest moons around the solar system's largest planets — the gas giants Jupiter,

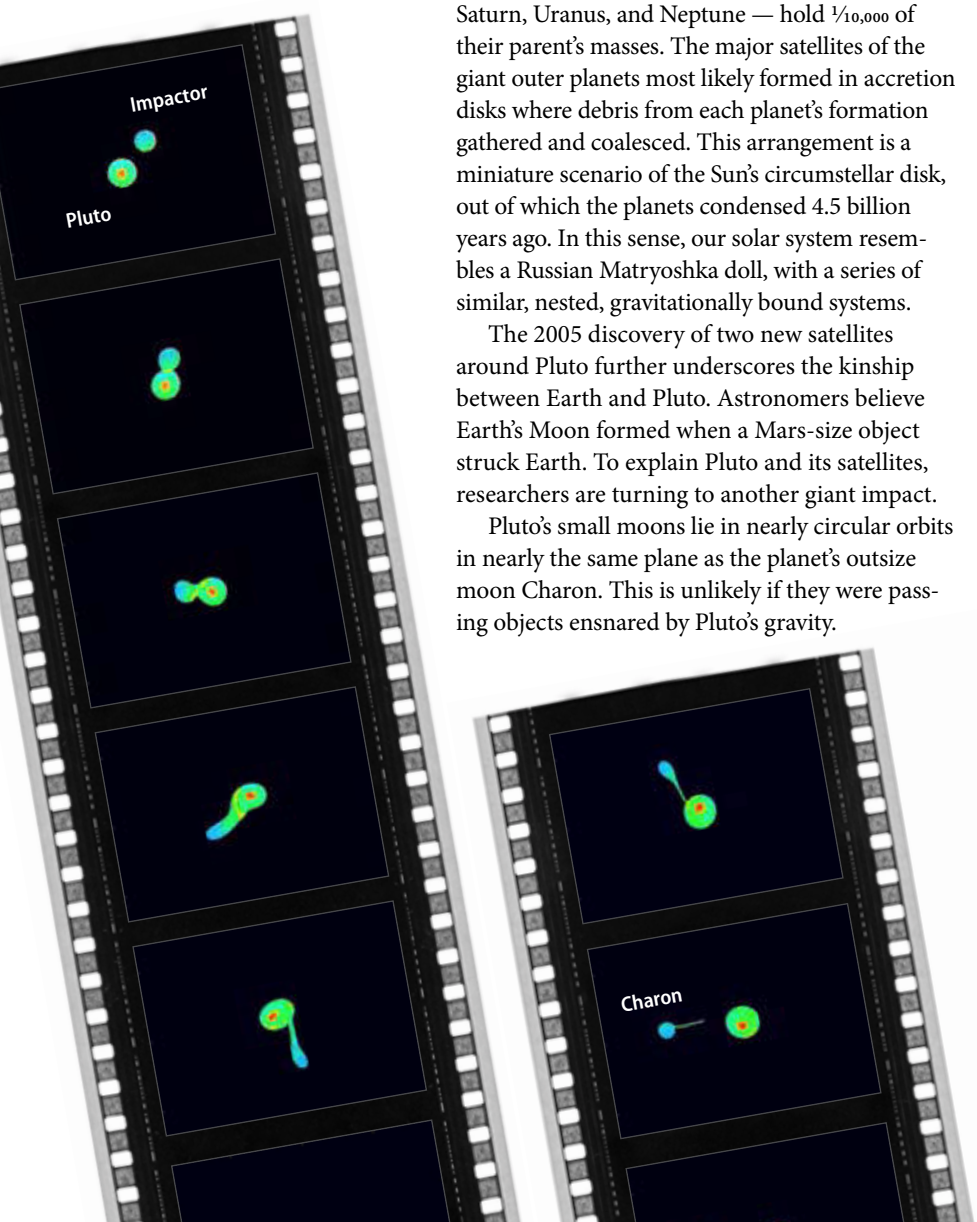
NASA'S NEW HORIZONS probe is slated to fly through Pluto's system in 2015. Earth and Pluto both have plus-size moons, leading astronomers to think of each system as a "double planet." Earth and Pluto may have each received a giant satellite-forming impact early in its history. DAN DURDA FOR *ASTRONOMY*

THE GALILEO spacecraft imaged Earth and the Moon, the solar system's other double planet, during a 1992 flyby. NASA/JPL/USGS

Saturn, Uranus, and Neptune — hold 1/10,000 of their parent's masses. The major satellites of the giant outer planets most likely formed in accretion disks where debris from each planet's formation gathered and coalesced. This arrangement is a miniature scenario of the Sun's circumstellar disk, out of which the planets condensed 4.5 billion years ago. In this sense, our solar system resembles a Russian Matryoshka doll, with a series of similar, nested, gravitationally bound systems.

The 2005 discovery of two new satellites around Pluto further underscores the kinship between Earth and Pluto. Astronomers believe Earth's Moon formed when a Mars-size object struck Earth. To explain Pluto and its satellites, researchers are turning to another giant impact.

Pluto's small moons lie in nearly circular orbits in nearly the same plane as the planet's outsize moon Charon. This is unlikely if they were passing objects ensnared by Pluto's gravity.



But if they aren't captured objects, then they must have formed from the same collision that gave birth to Charon. Astronomers think Charon formed as a result of a catastrophic collision between Pluto and a similar-size body not long after the planet formed. The impact threw debris into space that formed Charon and perhaps smaller satellites as well.

Orbits of moons formed this way become circular quickly — possibly in as little as a few hundred million years. The newly found satellites orbit in the same plane as Charon, which provides strong evidence for a common birth.

Big whacks

Prior to the Apollo lunar landings, scientists lacked information to distinguish among several theories for the Moon's origin. In the 1970s, ideas about the Moon's beginning converged on a collision-birth scenario. The Moon formed from debris created when a Mars-size object smashed into Earth. Lunar rock samples show that material similar to that found in Earth's mantle makes up the Moon.

Astronomers also were realizing, through increasingly sophisticated computer simulations, that many protoplanetary objects — the building blocks of planets — must have formed in the young solar system sunward of Jupiter. Some of these objects, which could have been as large as Mars, carried a significant proportion of Earth's mass.

In 1978, as the Earth impact theory was gaining acceptance, astronomers found Pluto's moon Charon. By the early 1980s, researchers were suggesting Charon formed in a similar large-body collision scenario. Then, in the early 1990s, the discovery of other icy bodies at Pluto's distance proved the reality of the Kuiper Belt, a hypothesized zone of icy debris between 30 and 50 times Earth's distance from the Sun. Neptune's intense gravity dominates the belt's inner region just as Jupiter's gravity dominates the asteroid belt's outer edge.

Although collisions in the dense and crowded inner portion of the young solar system seemed likely, astronomers aren't sure how common they were in the Kuiper Belt, which also was probably much more densely packed when it was young. Pluto and Charon provide important clues.

SIMULATING impacts on a computer lets astronomers examine different combinations of impactor speed and mass. Robin Canup's 2005 simulations of an early Pluto impact suggest an object nearly as large as Pluto itself gave rise to Charon. The moon likely formed intact as a direct result of the collision. SWRI

Multiple moons

Although astronomers estimate at least 10 percent of KBOs are binary objects, they assume most of them resulted from gravitational capture between two objects. However, astronomers have already found a Kuiper Belt object with two small satellites. In December, Caltech's Mike Brown found a second satellite orbiting a KBO known as 2003 EL_{61}, which is about one-third of Pluto's mass.

Many bodies similar to Pluto's size may turn out to be multiple systems. Xena, Pluto's bigger cousin, has one small satellite nicknamed Gabrielle. If this, too, formed by collision, smaller, as-yet-undetected satellites may orbit Xena as well. At present, though, Pluto is the only example of a Kuiper Belt quadruple-system.

For years, astronomers have used computer simulations to model the collision between two similar-size bodies. Some of the most recent and detailed have been done by Robin Canup of the Southwest Research Institute in Boulder, Colorado,

THE DISCOVERY OF PLUTO'S new satellites underscores the kinship between Pluto and Earth.

and her colleagues. For the purpose of understanding satellites around Pluto and elsewhere in the Kuiper Belt, the most interesting collisions are those in which the impacting body grazes its target and splatters stringy blobs of material into space.

Some modeled collisions produce a disk with a few percent of the central planet's mass. This disk extends far enough into space that tidal forces don't keep material smeared into a disk, such as at the rings of Saturn. Instead, the disk's debris quickly coalesces into an orbiting companion.

By 2001, simulations were detailed enough to show that a single impact by a Mars-size object in the late stages of Earth's formation could account for the Moon's chemical characteristics, especially its depleted iron content. The simulations also explained the relative masses and high angular momentum of the Earth-Moon system, where the developing Moon continues spiraling outward as Earth's rotation slows.

Canup recently modeled Pluto collision scenarios between two equal-size KBOs. In one simulation, as the rocky cores merge, a spiral arm of debris stretches out and forms a ring around the central mass. In another simulation, a fully intact moon containing 12 percent of the central planet's mass breaks off into orbit.

So, where did Pluto's smaller moons come from? One powerful line of evidence suggests the satellite pair formed during the same collision that produced Charon. Captured objects have strongly elliptical orbits. Even over a few billion years, Pluto's new satellites couldn't have turned elliptical orbits to the near-circular ones Hubble measured.

Moreover, all of Pluto's moons seem to be orbiting in the same plane, whereas captured bodies would orbit in different planes. Because changing an orbit's plane takes a large amount of energy, it's unlikely captured moons could have altered their orbits enough to circle in the same plane — and match Charon's orbital plane, too.

Other, smaller bodies could have formed in the collision, too, but they've gone undetected so far. Perhaps their orbits became unstable, and they crashed into Pluto or Charon. Any moonlets formed after the impact that gave rise to Earth's Moon might have had a similar fate, later crashing back to Earth or the Moon. Because Earth is embedded so deeply in the Sun's gravitational field, some of the impact debris may have gone into orbit around the Sun instead.

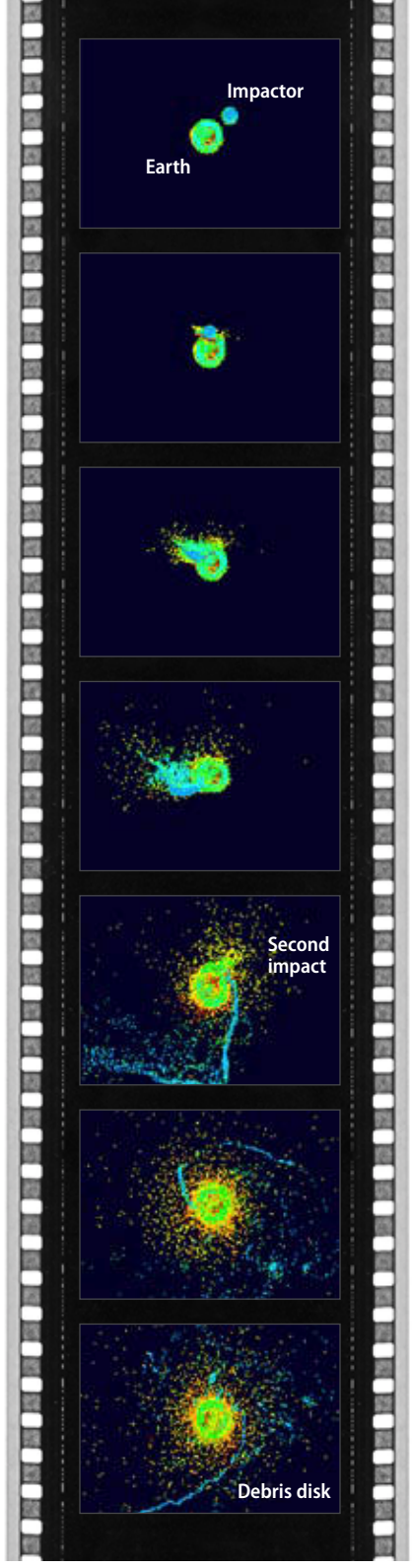
Consider, for example, the third-stage booster of the Apollo 12 Moon mission. Launched from Earth in November 1969, it propelled the Apollo capsule Yankee Clipper and the lunar lander Intrepid to the Moon. In 1971, it escaped the Earth-Moon system and went into solar orbit, but Earth's gravity recaptured the booster in 2002. Scientists expect it eventually will crash into the Moon. Similarly, any debris scattered during the Moon's formation may have been ejected and then later swept up.

Ring around Pluto?

Kuiper Belt debris must smash into Pluto's small satellites now and then. These impacts may blast off enough dust to form temporary ring systems. In December, astronomers using Hubble identified such a phenomenon at Uranus. They discovered a vast outer ring replenished by dust blasted off a newly discovered moon named Mab. Such rings or ring arcs around Pluto could pose a navigational hazard to the New Horizons spacecraft, which will race through the system in 2015.

New Horizons principal investigator S. Alan Stern of the Southwest Research Institute in Boulder describes the Pluto flyby as the capstone to humanity's 50-year initial reconnaissance of the solar system. It's fitting, then, that the final clues to the origin of Earth's Moon await us at the fringe of the solar system — and a decade in the future. A

ONLINE EXTRA Watch simulations of collisions that may have given Earth and Pluto their moons at www.astronomy.com/toc.



THE MOON'S formation was a messy affair. The best explanation, say scientists, is that an object nearly the size of Mars first struck Earth a glancing blow, then hit our planet again and merged with it. Some of the debris thrown out by the impact orbited Earth. The Moon formed out of this disk of matter. SWRI

BY MARTIN RATCLIFFE AND ALISTER LING

JUNE 06

Both the innermost and outermost planets put on good shows this month, competing with Jupiter for observers' attention.

The rise and fall of Mercury

It takes just 3 or 4 weeks for the solar system's innermost planet to pop into view, swing through a short arc in the evening twilight, and slump back into the Sun's glare. Unlike the outer planets, which offer several months of good viewing, you need to plan carefully to catch fleet-footed Mercury. ☾ First, choose a spot with an unobstructed view toward the west-northwestern horizon. Mark the point on the horizon where the Sun sets. Return 30 to 45 minutes later with binoculars and scan just above your mark. You won't miss the bright, peach-colored dot glowing against the orange twilight. Mercury will be tough to see before May 27, but it gets easier with each passing day as the planet moves farther from the Sun and climbs higher in the darkening sky.

MERCURY APPEARS BEST on June evenings, when it shines brightly low in the west-northwest. GEORGE LIVADARAS

After mid-June, Mercury dims quickly. Although the planet draws closer to Earth, its phase wanes from gibbous to a thin crescent, leaving less surface to reflect sunlight our way.

Next, swing your binoculars to the upper left and land on bright yellow Saturn. It sits next to a patch of flickering stars nicknamed the Beehive Cluster (M44). During the first 2 weeks of the month, the cluster slides to the lower right toward orange Mars, forming a wonderfully tight grouping June 15. Saturn crawls away from the Beehive while speedier Mars overtakes it on the 17th.

This is your last chance before autumn to get a decent look at Saturn and its amazing rings through a telescope. The closer it gets to the horizon, the more Earth's turbulent atmosphere blurs the view. Mars appears tiny compared with the ringed planet, so you'll be lucky even to tell the Red Planet's disk has a phase like our Moon a few days before full. As the curtain falls on this planetary trio on the 27th and 28th, a crescent Moon joins the party.

Befitting its role as king of the planets, Jupiter commands the southern sky as darkness falls. Much fainter but still bright, the blue-white star Spica shines to the planet's right. A little farther to the left lies orange Antares, the heart of the celestial Scorpion. Watching the shifting features in Jupiter's cloud tops and the graceful orbital dance of its four bright moons never loses its charm. Sometimes, one or two moons hide from view in front of or behind the giant planet.

A waxing gibbous Moon passes 5° below Jupiter June 8. From one night to the next, the Moon treks low across the south, taking on a slight yellow color as all objects do close to the horizon. If our nocturnal companion seems lower than usual, it is. The Moon's orbit shifts around the sky in an 18.6-year cycle, and we're at the bottom of the cycle now.

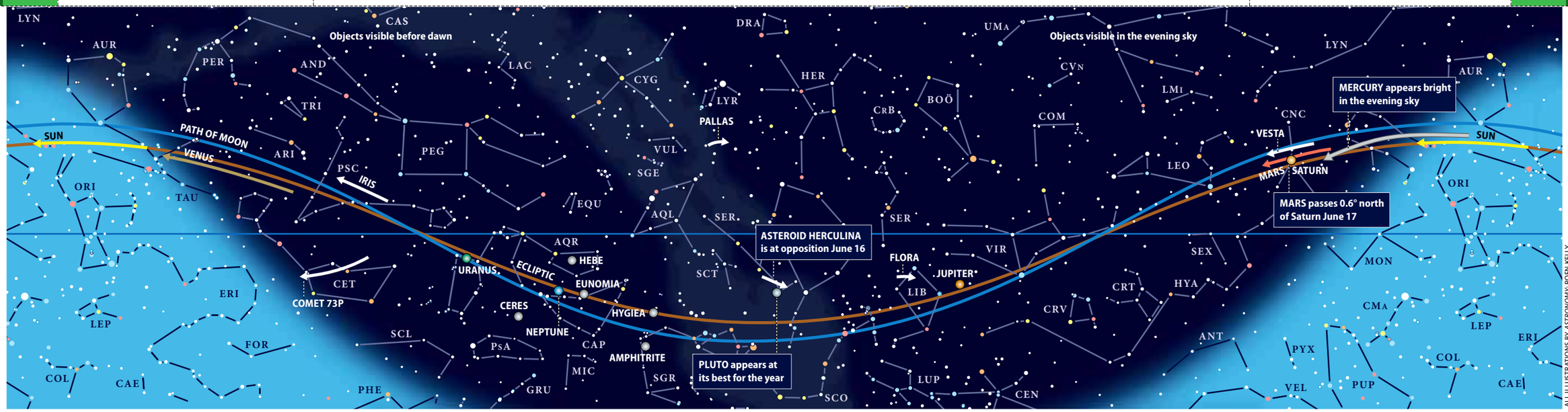
Thanks to media hoopla, it's hard to miss the arrival of the summer solstice, which occurs at 8:26 A.M. EDT June 21. The solstice marks the start of summer in the Northern Hemisphere. The Sun reaches its highest point in the sky at local noon, marking the longest day of the year.

An obvious consequence of the summer solstice is short nights, which don't leave much time for observing. Many backyard astronomers realize what you observe doesn't matter so much as how often. The more you do it, the better you feel. Consider buying a solar filter and looking at solar activity. Hydrogen-alpha filters now cost the same as a high-end eyepiece and will deliver a fantastic observing experience. And remember — never view the Sun directly without a quality solar filter.

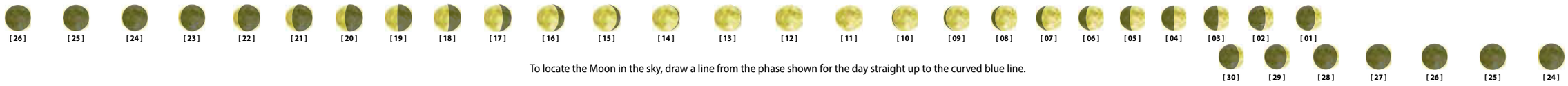
Pluto reaches opposition June 16, when the outermost planet lies opposite the Sun in our sky. Many observers consider it a feather in their cap to track Pluto's footsteps from one night to another. Wait until midnight, when the planet lies highest in the south, before taking the challenge.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

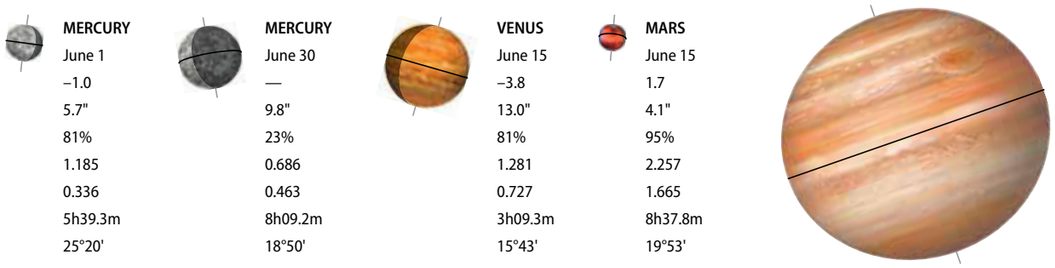


ALL ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY



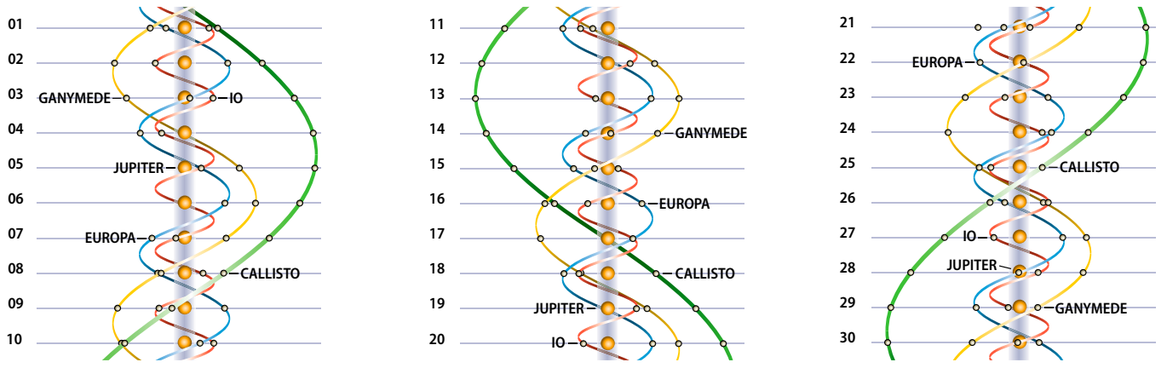
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	• PLUTO
Date	June 1	June 30	June 15	June 15	June 15	June 15	June 15	June 15	June 15
Magnitude	–1.0	—	–3.8	1.7	–2.4	0.4	5.8	7.9	13.9
Angular size	5.7"	9.8"	13.0"	4.1"	42.5"	16.9"	3.5"	2.3"	0.1"
Illumination	81%	23%	81%	95%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.185	0.686	1.281	2.257	4.638	9.831	19.896	29.473	30.121
Distance (AU) from Sun	0.336	0.463	0.727	1.665	5.413	9.137	20.081	30.055	31.127
Right ascension (2000.0)	5h39.3m	8h09.2m	3h09.3m	8h37.8m	14h30.2m	8h43.9m	23h04.6m	21h28.2m	17h41.0m
Declination (2000.0)	25°20'	18°50'	15°43'	19°53'	–13°31'	18°55'	–6°46'	–15°08'	–15°42'



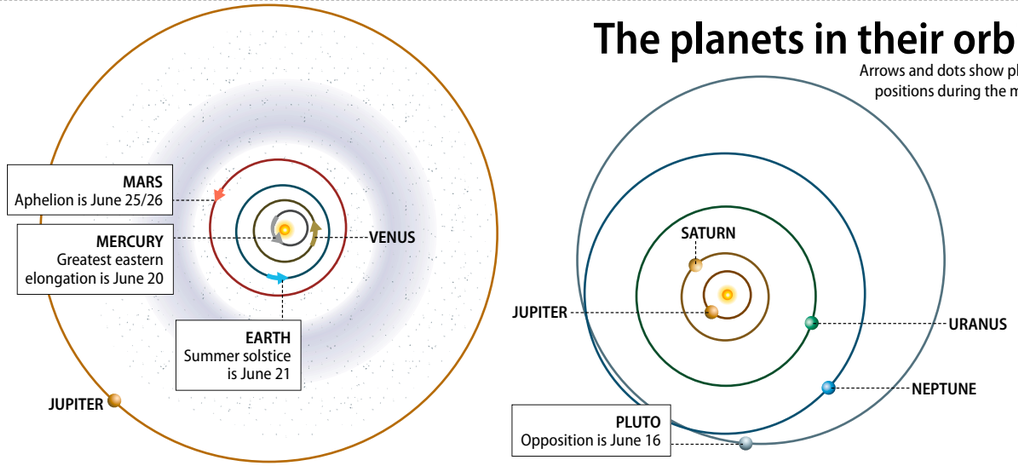
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on date shown. South is at top to match the view through a telescope.



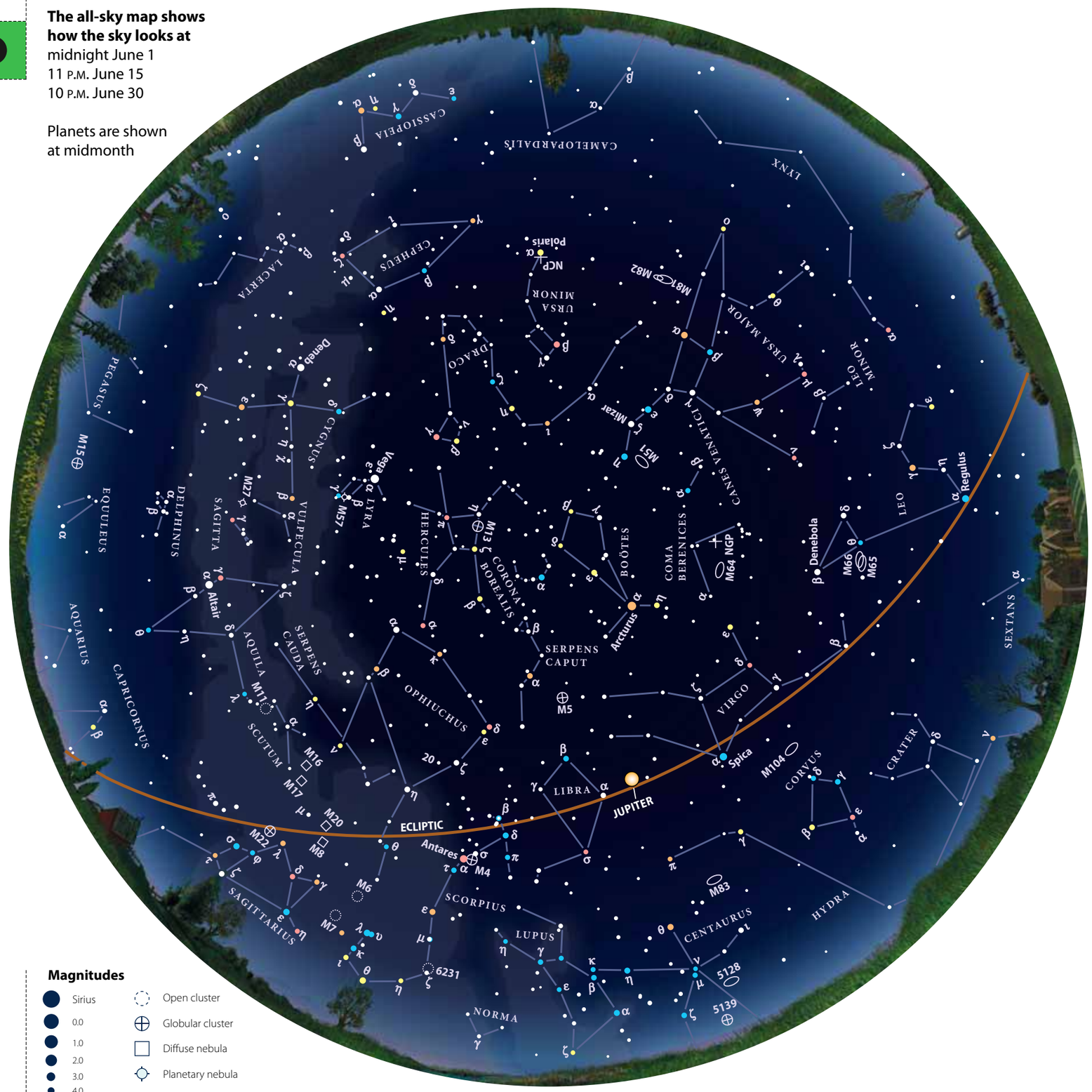
The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
midnight June 1
11 P.M. June 15
10 P.M. June 30

Planets are shown at midmonth



Magnitudes

Sirius	Open cluster
0.0	Globular cluster
1.0	Diffuse nebula
2.0	Planetary nebula
3.0	Galaxy
4.0	
5.0	

This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

june 06

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				[01]	[02]	[03]
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ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

03 First Quarter Moon occurs at 7:06 P.M. EDT

The Moon is at apogee (251,084 miles from Earth), 9:40 P.M. EDT

07 The Moon passes 0.1° north of Spica, 5 A.M. EDT

08 The Moon passes 5° south of Jupiter, 3 P.M. EDT

10 The Moon passes 0.1° south of Antares, 7 P.M. EDT

11 Full Moon occurs at 2:03 P.M. EDT

16 The Moon is at perigee (229,236 miles from Earth), 12:59 P.M. EDT

Pluto is at opposition, 1 P.M. EDT

Asteroid Herculina is at opposition, 4 P.M. EDT

17 The Moon passes 0.6° south of Uranus, 1 P.M. EDT

17 Mars passes 0.6° north of Saturn, 7 P.M. EDT

18 Last Quarter Moon occurs at 10:08 A.M. EDT

20 Mercury is at greatest eastern elongation (25°), 4 P.M. EDT

21 Summer solstice occurs at 8:26 A.M. EDT

22 The Moon passes 6° north of Venus, 11 P.M. EDT

25 New Moon occurs at 12:05 P.M. EDT

Mars is at aphelion (154.9 million miles from the Sun), 9 P.M. EDT

27 The Moon passes 5° north of Mercury, 10 A.M. EDT

28 The Moon passes 3° north of Saturn, 7 A.M. EDT

The Moon passes 2° north of Mars, 5 P.M. EDT

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

THE DEEP SKY

The jewels of the Northern Crown can best be described as understated. You won't find any bling in this constellation.

Corona Borealis delights

Think of a visit to the Northern Crown as you might a stroll in the neighborhood park. Don't expect to see any jaw-dropping national monument of clusters, galaxies, or gas clouds, but, instead, enjoy the local charm.

Although you can best appreciate the Crown's graceful arc from a dark site, the view through binoculars from a suburban backyard will do just fine. Slide back and forth along the tight arc of seven stars, and compare the colors of each semi-precious stone. Ignore for the moment that the only part of the Crown you can see from a big city without optical aid is its brightest star, Alpha (α) Coronae Borealis, also known as Alphecca or Gemma.

Falling off the precipice

This small constellation's most fascinating star is the variable R Coronae Borealis. At unpredictable intervals, R CrB coughs up a layer of carbon soot so thick, its brightness plunges an amazing 8 magnitudes. At maximum, the star glows around 6th magnitude — barely visible to the naked eye from a dark site. R "Cor Bor" often takes a step down to magnitude 6.5 for a day or so before jumping off the proverbial cliff. Take a few seconds to give it a peek as your eyes begin to dark-adapt.

An 8-inch scope has enough light-gathering power to show you the star's color changing from light orange to deep red before it becomes too faint to trigger your eyes' color receptors. On its last crash, which started January 10, 2003, it took only 10 nights to reach bottom. Episodes can come as soon as 400 days apart, which means the next plunge could occur anytime. If you catch R CrB on its descent, keep tabs on it every hour or two — this is astrophysics in action. The American Association of Variable Star Observers has free star charts on its web site (www.aavso.org) to help you follow the star's dive.

If you have access to a high-end 6-inch refractor or a sharp 8- to 10-inch reflector, try to split two tight double stars in Corona Borealis: Eta (η) and Gamma (γ) CrB . With separations of just 0.5" and 0.7", respectively, these two require fine optics and a steady atmosphere to allow magnifications up to around 500x.

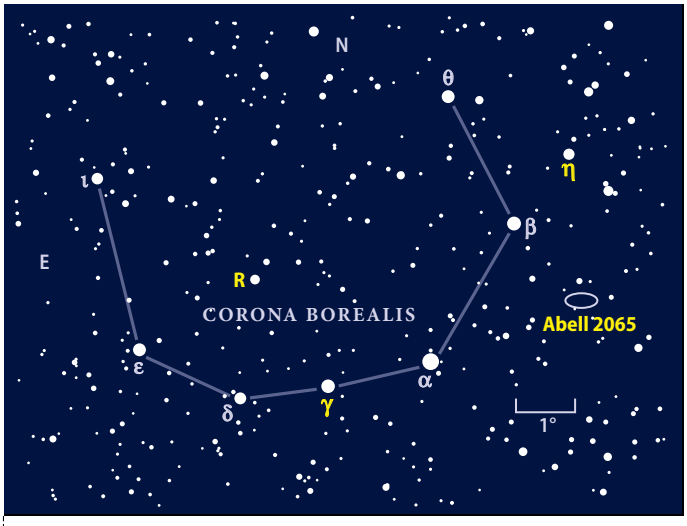
Going far

A deeply buried treasure hides in this part of sky: the distant collection of galaxies known as the Corona Borealis Cluster, or Abell 2065. More than 100 galaxies pack into an area just 20' across. The galaxies flicker dimly across 1.5 billion light-years of space — the brightest appears as a feeble glimmer at 16th magnitude.

Deep-sky observer Steve Gottlieb managed to eke six galaxies out of the background during an hour of concentrated observing. He pushed his 17.5-inch scope to the limit on a 7,000-foot mountaintop east of San Francisco. Astronomy has a strangely wonderful way of touching the mind like no other hobby — it can give an incredible rush to see almost nothing.

DSS

THE CORONA BOREALIS GALAXY CLUSTER lies more than a billion light-years away and contains hundreds of island universes.



ASTRONOMY: ROEN KELLY

CARBON-RICH R CORONAE BOREALIS vies with distant galaxy cluster Abell 2065 for deep-sky supremacy in Corona Borealis.

THE PLANETS

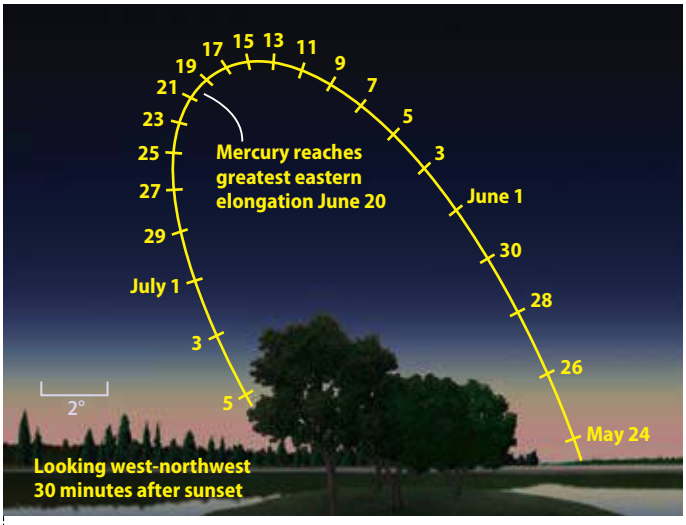
Earth's summer solstice arrives in June, along with views of the other eight planets. If you're up for a challenge, try to complete a tour of the entire solar system in one night.

Start your solar system tour in the evening sky, about 45 minutes after the Sun sets. You can spend the entire month watching **Mercury** go through a full range of changes. For Northern Hemisphere observers, this ranks among Mercury's best evening apparitions of the year. These excellent conditions arise because this month the planet reaches both greatest elongation from the Sun (25° on June 20) and its farthest point north of the ecliptic (7° on June 1).

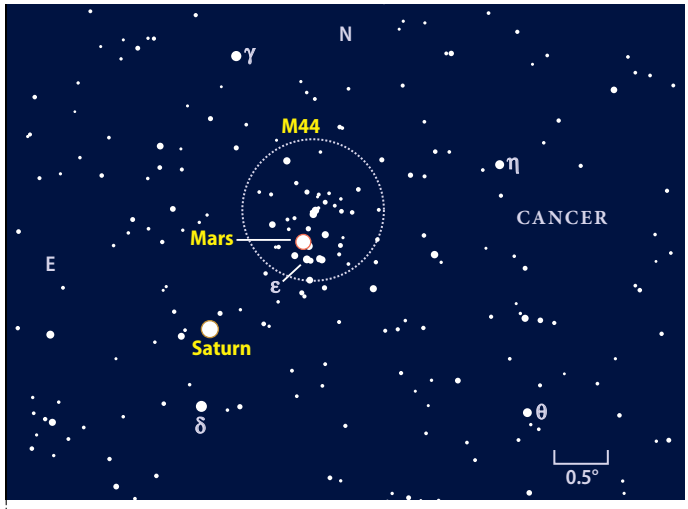
On the 1st, at about 9 P.M. local daylight time, you'll find Mercury low above the west-northwestern horizon. It shines brightly at magnitude –0.9. If you have a clear horizon, swing your telescope to this planet to spy its 78-percent-lit disk. Throughout June, the phase shrinks as Mercury draws closer to Earth.

In early June, Mercury climbs through Gemini the Twins, approaching its brightest stars, Castor and Pollux. By June 8, Mercury lies near 3rd-magnitude Epsilon (ε) Geminorum, a star visible only with binoculars as the sky darkens. Mercury appears brighter than the star despite having faded to magnitude –0.3. For a day or so on either side of June 11, Mercury forms an isosceles triangle with Castor and Pollux. The stars then mark the upper baseline, and Mercury sits at the triangle's tip, pointing toward the horizon. Mercury outshines both stars by a full magnitude or more and sets an hour and a half after the Sun.

On June 14, a telescope shows Mercury's 50-percent-lit disk. Mercury reaches greatest elongation June 20, when it stands 25° east of the Sun,



MERCURY CLIMBS HIGH in the evening sky this month for one of its best apparitions of 2006. *ASTRONOMY:* ROEN KELLY



ASTRONOMY: ROEN KELLY

ON THE EVENING OF JUNE 15, Saturn joins Mars in the vicinity of the Beehive star cluster (M44).

shines at magnitude 0.5, and appears 38-percent illuminated. As Mercury shrinks to a crescent, it dims rapidly and becomes harder to see in the evening twilight.

On June 27, the innermost planet shines at magnitude 0.9 and lies almost in line with Castor and Pollux. If Mercury is hard to find in the bright twilight, look for the slender crescent Moon — Mercury stands 6° below its silver sliver.

Mars crosses Cancer the Crab and catches up with Saturn during June. The Red Planet now shines like a moderately bright star, at magnitude 1.7, and its apparent size has dwindled to a mere 4". The tiny disk has little to offer telescope users. However, its ruddy presence within the Beehive star cluster (M44) June 15 holds considerable interest for viewers with binoculars and rich-field telescopes. The relatively bright orange light glows like a firefly nestled amid distant lights. That same night, **Saturn** stands 1.2° southeast of Mars.

Two nights later, on June 17, Mars passes 0.6° north of brighter Saturn. Low-power, rich-field telescopes will show both planets in the same field of view. Mars is the foreground object, lying 212 million miles from Earth, while Saturn lies 917 million miles away. Even though it's more than 4 times farther away, Saturn's disk appears larger than Mars' because of its physical superiority. The ringed planet spans 75,000 miles, some 18 times larger than Mars.

Saturn soon descends into the evening twilight, setting 2 hours after the Sun by June's close. Turbulence in Earth's

atmosphere will hinder views of the planet. Still, you should get a nice look at its rings and moons for a couple of hours each evening in early June, before the planet sinks too low. This is not the case for **Jupiter** — now rising in the southeast with Libra.

Gleaming at magnitude –2.4, Jupiter dominates the eastern half of the sky. It remains near its peak for the year following last month's opposition, when it came closest to Earth. Jupiter's apparent diameter shrinks less than 10 percent this month, remaining above 40". It's the largest planetary disk visible, both in the eyepiece and in reality. Jupiter's clouds offer so much detail through small scopes that they will please everyone, especially observers patient enough to wait for fleeting moments of stillness in Earth's atmosphere.

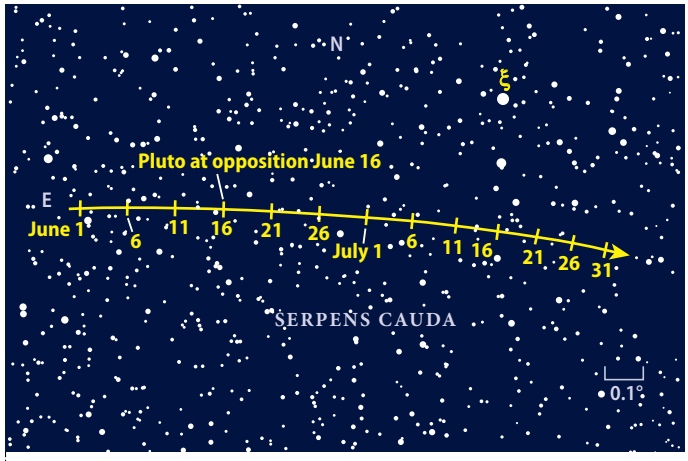
If you want to get more serious in your Jupiter observing, try estimating when any visible feature crosses the imaginary line bisecting the planet from pole to pole — called the central meridian. Even beginners can achieve 10-minute accuracy. Your precision will improve with experience.

Another good exercise is tracking Jupiter's moons. Their relative positions can be found on the fold-out map in the magazine's center. Particularly exciting are times when a moon enters an eclipse, transit, or occultation. The best events are shadow transits of the moons. Each moon casts a shadow, and, if the alignment is right, the shadow falls on Jupiter's visible face. The shadow appears as a black dot crossing the disk in a matter of hours. Io's shadow, for example, appears approximately every 42 hours, although not all transits can be seen from one Earth location.

NEW HORIZONS began its journey to Pluto January 19. When it arrives in 2015, it will give humans their first close look at this strange world. NASA

Pluto, the ninth planet and second-largest Kuiper Belt object known, reaches opposition June 16. On June 1, it lies 1.3° almost due east of Xi (ξ) Serpentis. During the first week of June, you'll find a 7th-magnitude star near Pluto that serves as a guide to locate the correct field of view. Pluto's retrograde motion carries it westward to within 0.6° southeast of Xi Serpentis by June's end. The gap will continue to close during July.

Pluto glows at magnitude 13.9, making it similar to many stars in this Milky Way region. As a result, it's a challenge to spot. An 8-inch telescope on a perfect night brings Pluto to the edge of visibility. For a direct view, however, you'll want to use at least a 10-inch scope. Pluto lies 2.8 billion miles from Earth at opposition, its closest approach of the year.



PLUTO BECKONS during June, but you'll need an 8-inch or bigger scope to spy its 14th-magnitude glow.

Distant **Neptune** glows at magnitude 7.9 from within the confines of Capricornus the Sea Goat. It rises near local midnight, and binoculars will reveal it once the planet climbs high enough, about 2 hours later. First, look for Iota (ι) Capricorni, a 4.3-magnitude star in the upper eastern half of the group. Neptune lies about 2° northeast of the star. Toward the end of June, Neptune approaches a star of similar brightness, which makes it easier to watch the planet's motion relative to the background sky from night to night.

The motion of **Uranus** against the background stars slows to a halt this month, as the planet turns west for its retrograde loop. June 19 marks the end of Uranus' easterly motion. From then on, its westerly pace increases weekly. The planet's sluggish pace keeps it 3° east of Lambda (λ) Aquarii and 1° north of the 5.4-magnitude multiple star 83 Aquarii all month. Uranus glows at magnitude 5.8, an easy target for binoculars and just within reach of the naked eye from a dark site.

Venus appears dazzling in June's dawn sky. The month opens with Venus shining at magnitude –3.8 and showing a 76-percent-lit disk, which waxes to 85-percent lit by June 30. The planet tracks through southern Aries and enters Taurus June 18. Its location near the Pleiades star cluster (M45) makes a stunning sight as dawn breaks. Don't miss the view the morning of June 22, when Venus lies 6° south of M45 and a crescent Moon lies 8° west-northwest of Venus. The following morning, the waning Moon lies 5° east of M45. Venus joins the Hyades star cluster on the last day of June, when it stands 4° northwest of Taurus' brightest star, 1st-magnitude Aldebaran.

The summer solstice occurs at 8:26 A.M. EDT June 21. This marks the moment when the Sun lies farthest north of the celestial equator during its annual trek along the ecliptic, and heralds the longest day.

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*

METEORS AND MOONS

A highly variable meteor shower — which occasionally produces strong activity — peaks late this month when the Moon is gone from the sky.

Herdsman's siren call

Recent unforeseen activity makes the annual June Boötid meteor shower worth observing. Normally active from June 26 to July 2, an outburst in 2004 surprised everyone by producing meteors June 23, before any previous historical Boötid activity.

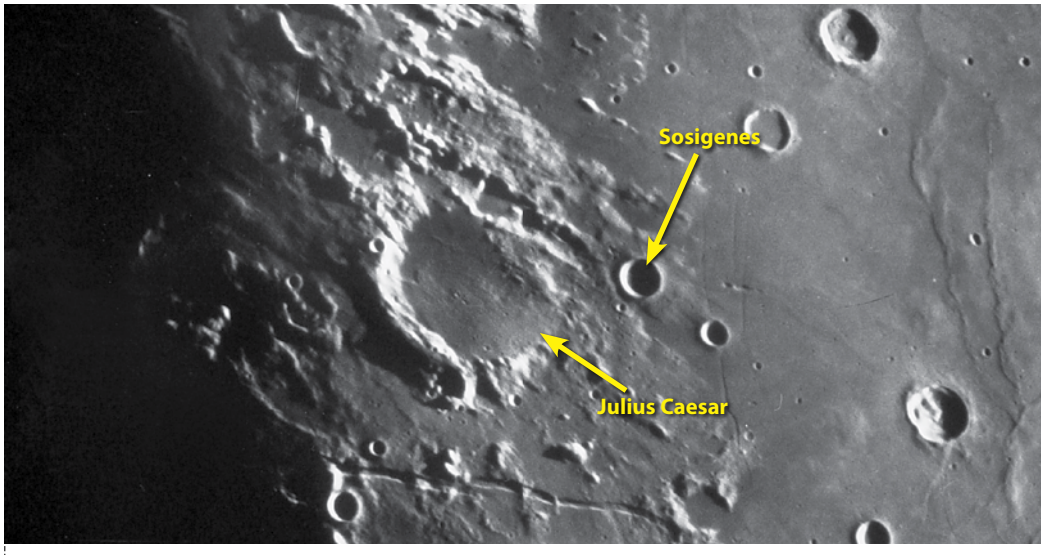
The shower derives from debris ejected by Comet 7P/Pons-Winnecke. Following several decades of dormancy, the shower awoke with a vengeance in 1998. The comet last reached perihelion — its closest approach to the Sun — in 2002, and will return to the inner solar system in 2008.

It's fair to say there may be little or no activity this year. Nevertheless, sky conditions will be near perfect. The radiant lies nearly overhead when darkness falls, and the June 25 New Moon avoids moonlight interference. Even after midnight, the constellation Boötes the Herdsman stands high in the western sky. Look for the characteristically slow Boötid meteors at any time of night. The unpredictable nature of this shower offers an element of surprise for observers.

Hail Caesar

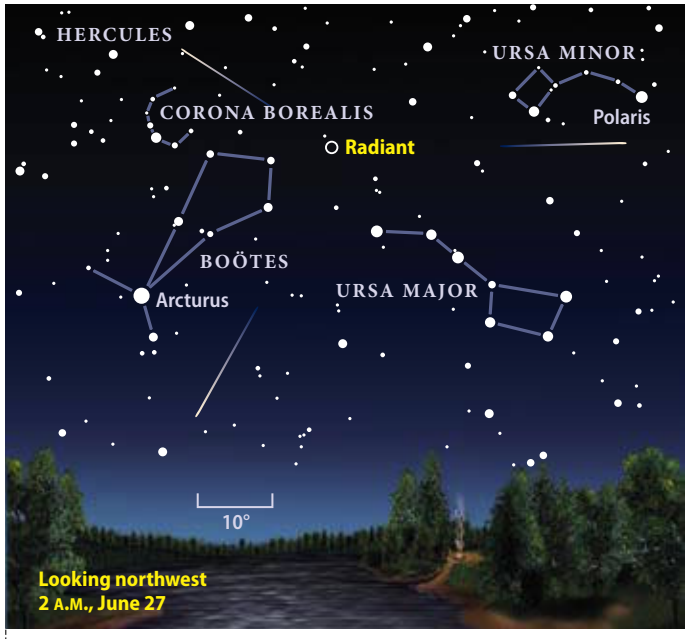
The ancient crater Julius Caesar stands west of Mare Tranquillitatis. The crater's walls and floor have been partly obliterated, and the southeastern wall no longer exists. A small, younger crater, Sosigenes, lies just outside where they once would have stood. Notice the striated appearance of this region's ridges — all align southeast to northwest and radiate away from the Imbrium basin. When the huge impactor that formed the Imbrium basin struck, blast debris carved the region around Julius Caesar into its present appearance — wiping out the crater's wall and eroding the region's hills into their battered and aligned state.

Since the Imbrium impact, lava has covered the floor of the 56-mile-wide Julius Caesar, and tiny impact craters, visible in larger scopes, are dotted all around. Under low lighting conditions, the Ariadaeus Rille stands out well just to the crater's south. This wide rille stretches about 135 miles and ranks among the best such features on the Moon. You'll see sunrise over this region June 2 and again July 1.



FROM *CONSOLIDATED LUNAR ATLAS* (LPL/UA)

BATTERED CRATER JULIUS CAESAR lies along the western shores of Mare Tranquillitatis. It makes a fine sight just before First Quarter Moon.



ASTRONOMY: ROEN KELLY

THE BOÖTID METEOR SHOWER may delight observers in late June, or may be a dud.

COMETS AND ASTEROIDS

The Strongman receives a visit from an 11th-magnitude comet, while the brightest asteroid plies space in front of the magnificent Beehive star cluster (M44).

The unknown Hercules

Early on in their observing careers, most novice stargazers learn to find the keystone of Hercules and its splashy globular star cluster, M13. The area to the southeast (lower left as seen from the Northern Hemisphere), tends to remain unexplored thanks to its lack of bright stars and deep-sky objects. With the passage of Comet C/2004 B1 (LINEAR) through the territory, however, you have a good reason to go exploring.

The comet appears highest in the late-evening sky, so the best time to track down this primordial snowball is in late May when the Moon remains a thin crescent. Because C/2004 B1 never brightens past 11th magnitude, you'll need to get out under a dark sky to spot its ghostly fuzz. If you can spy some NGC companions to the Virgo cluster's Messier objects in your scope, then you should be able to nab the comet.

On the evening of May 30, look for the comet 1° north of 95 Herculis, a double star with nearly equal components separated by 6". This double is easier to split than the thin gap of the famous Double Double in Lyra but considerably tougher than colorful Albireo, the eye of Cygnus the Swan. One finder field to the north of 95 Herculis lies 100 Her, a pair of identical 6th-magnitude stars with a comfortable 14" spread.

Comet C/2004 B1 should meet its match the night of June 1, when it lies in the field of elliptical galaxy NGC 6482. The two should look remarkably similar in brightness, shape, and structure. If you were comet-hunting, would you be able to tell which was which? Well-known author and comet-discoverer David Levy has just published *Deep Sky Objects: The Best and Brightest from Four Decades of Comet Chasing*, a book about the sights that slide into the eyepiece while sweeping the sky for comets.

Comet survivor?

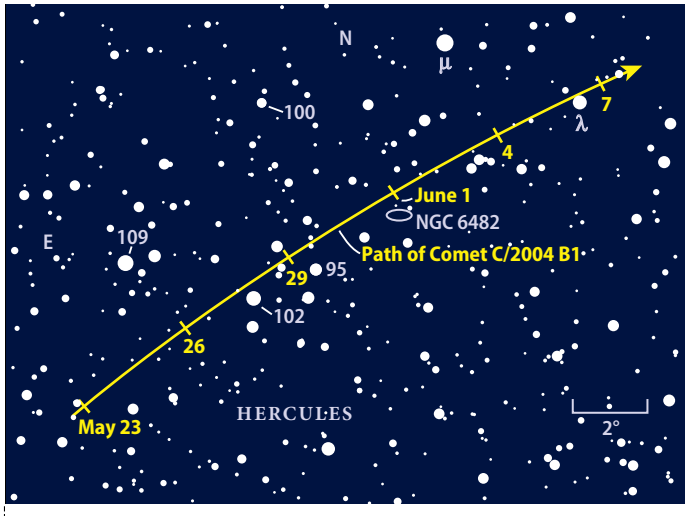
Thanks to favorable geometry, observers in the Southern Hemisphere now are in the best position to monitor the last days of Comet 73P/Schwassmann-Wachmann 3. In early March, astronomers discovered four new pieces of the comet's split nucleus, bringing the total number known to seven.

Will the comet be able to survive its punishing pass through perihelion in early June? If so, it could return for another round of solar heating in 5 years. Or, what seems more likely, will the Sun's heat shred it into several dust trails?

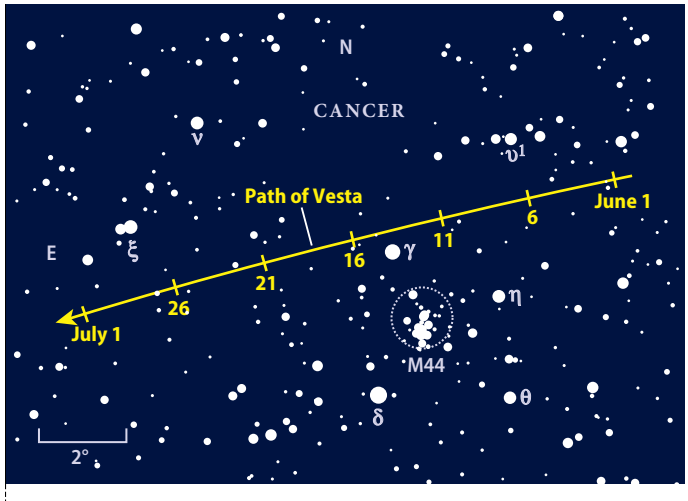
Vesta buzzes the Bees

At the heart of the small constellation Cancer the Crab lies M44, an open star cluster known as both the Beehive and Praesepe. This group appears as a misty cloud to the unaided eye under a dark sky but resolves into a few dozen sparkling stars with the smallest optical aid. Asteroid 4 Vesta shares the same binocular field during the first 2 weeks of June (as do the planets Mars and Saturn), but you'll really need a telescope to track down the 8th-magnitude space rock.

This main-belt asteroid spans 320 miles and rotates once in just 5.34 hours. Vesta skims the heart of the 12th-magnitude spiral galaxy NGC 2599 the night of June 8; it's a tough sight visually, but easy fodder for a CCD portrait.



COMET C/2004 B1 glides through Hercules this month. It's a nice target for observers with big scopes under dark skies.

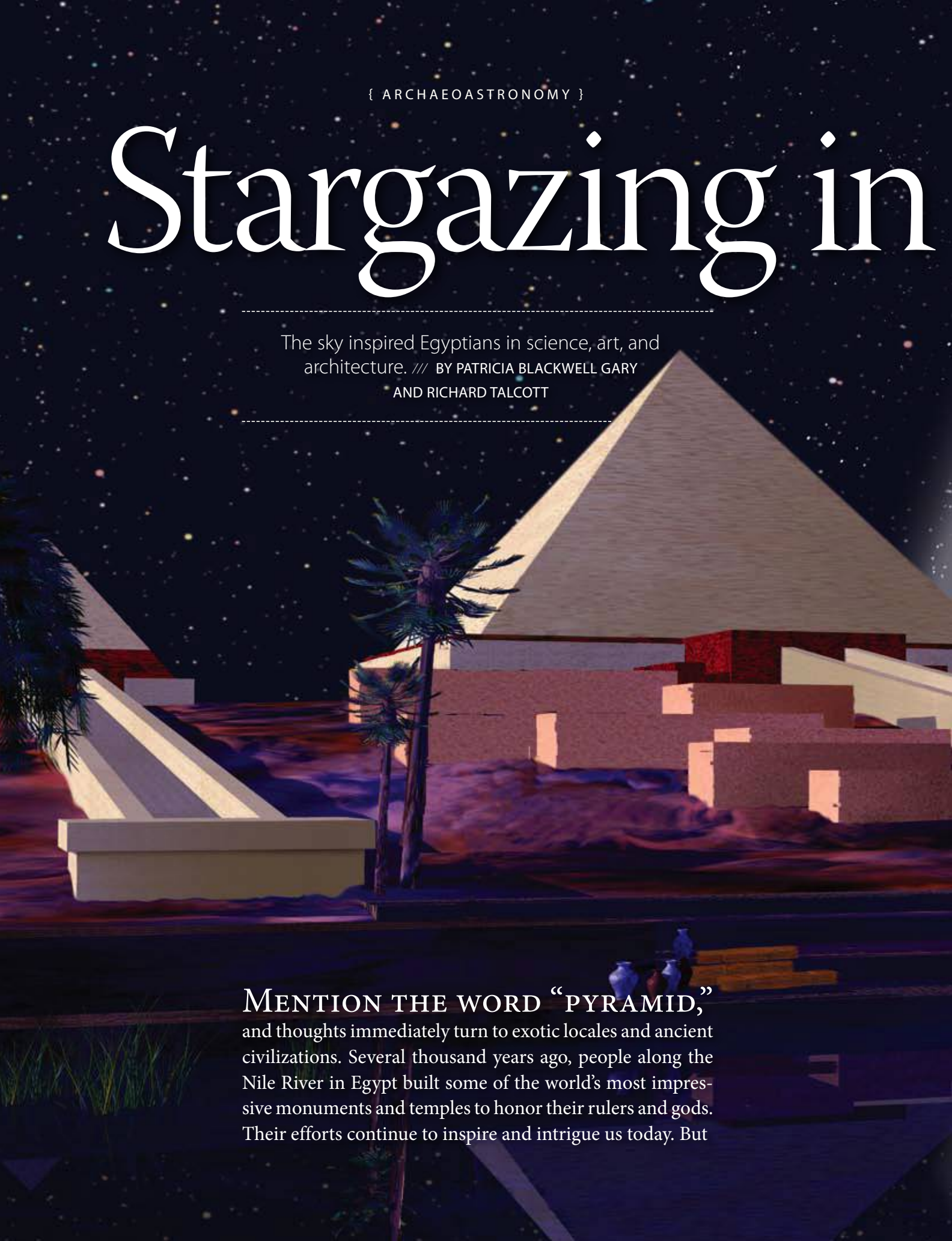


ASTEROID VESTA tracks near the Beehive star cluster (M44) during early June, adding a little splash to an already splashy cluster.

{ ARCHAEOASTRONOMY }

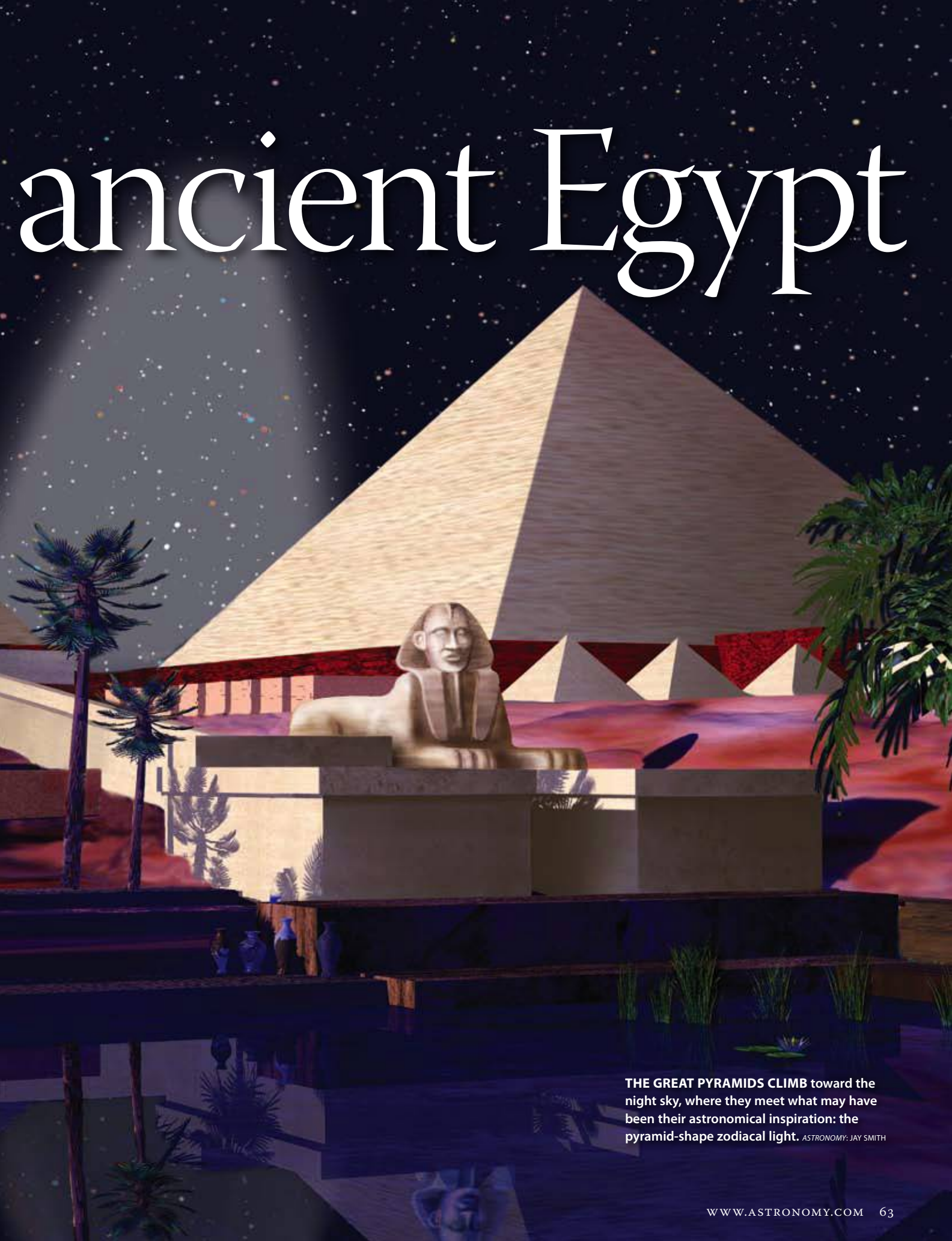
Stargazing in

The sky inspired Egyptians in science, art, and architecture. /// BY PATRICIA BLACKWELL GARY AND RICHARD TALCOTT



MENTION THE WORD "PYRAMID," and thoughts immediately turn to exotic locales and ancient civilizations. Several thousand years ago, people along the Nile River in Egypt built some of the world's most impressive monuments and temples to honor their rulers and gods. Their efforts continue to inspire and intrigue us today. But

ancient Egypt



THE GREAT PYRAMIDS CLIMB toward the night sky, where they meet what may have been their astronomical inspiration: the pyramid-shape zodiacal light. *ASTRONOMY*: JAY SMITH

AN OBELISK STANDS GUARD over the sacred lake of the Temple of Amun in Karnak. HEIDI GRASSLEY

A SUN PILLAR would have been a dazzling sight to the ancient Egyptians — as it is to us today. The shape could have inspired the creation of obelisks. RANDALL WEHLER

what inspired the art and architecture of the ancient Egyptians?

Unfortunately, the origins of the Egyptians' religious beliefs and how they were translated into art and architecture remain lost in the mists of prehistory. Most Egyptologists think observations of the natural world played a key role — after all, the sun-god Re was their greatest deity. We believe two icons of Egyptian architecture — the pyramid and obelisk — were inspired by previously overlooked astronomical phenomena connected with sunrise and sunset: the zodiacal light and Sun pillars, respectively.

To the ancient Egyptians, keen observers of nature during the day, it was natural to extend their observations to the one aspect of nature conspicuous at night — the star-filled sky. In the clear desert air of ancient Egypt, before the modern scourge of light pollution, the starry realm would have commanded the attention of any inquisitive person. Phenomena that typically go unnoticed today would have been obvious to anyone who looked. As in all primitive cultures, the sky was both an integral part of daily life and a presence of cosmic power.

The early Egyptians saw in the Sun, Moon, and stars patterns of continuity: birth, death, and resurrection. Symbolically, the religious values assigned to these celestial objects inspired awe and adoration, but knowledge of them also had practical applications. The sky served as map, clock, and calendar.

The Dog Star

Confirmation of the ancient Egyptians' skygazing comes from their observations of the bright star Sirius, known to them as Sothis. Around 3000 B.C., Sirius disappeared in the Sun's glow at solar conjunction in late spring. It then reappeared in the eastern sky before dawn near the time of the summer solstice. This so-called heliacal rising heralded the coming flood of the Nile. The annual inundation deposited thick, rich mud, an event upon which agriculture — and all life in Egypt — depended. The Egyptians memorialized Sirius' heliacal rising by making that date the start of their calendar year.

The appearance of Sirius in the sky had practical benefits. But the solar cult developed by the Egyptians extended far beyond the life-giving qualities of our star. Even in the Neolithic period (about 7000–4000 B.C.), Egyptian graves were erected to face the rising Sun, perhaps to provide energy for the dead.

By the fourth dynasty, which ran from approximately 2575–2465 B.C., Re had ascended to chief god. Egyptian kings held the title "Son of Re." The Pyramid Texts — a collection of prayers, hymns, and spells inscribed in the pyramids' inner chambers — tell of how the Sun's rays would transport the king to heaven. That held extreme importance to the Egyptians, who believed life on Earth was but a brief interlude compared with the eternal life ahead.

The center of the solar cult was at Heliopolis in Lower Egypt. Worship in the great temple there, and at other Sun temples throughout Egypt, centered on a sacred icon known as the *benben*, a squat, cone-shape stone placed in full sunlight. The word *benben* also signified the capstone of a pyramid and the tip of an obelisk. Clearly, this was a culture devoted to sunlight, and whose monuments incorporated aspects of that Sun worship.

The Egyptians held reverence for the places where the Sun rose and set. The hieroglyph for their word *akhet*, typically translated as "horizon," shows the Sun's disk between two mountains. But to the Egyptians, this told only part of the story. *Akhet* was the place where the Sun was reborn each day, and, by extension, the location where the king would be reborn after death. The *akhet*'s shape even found its way into temple art and construction.

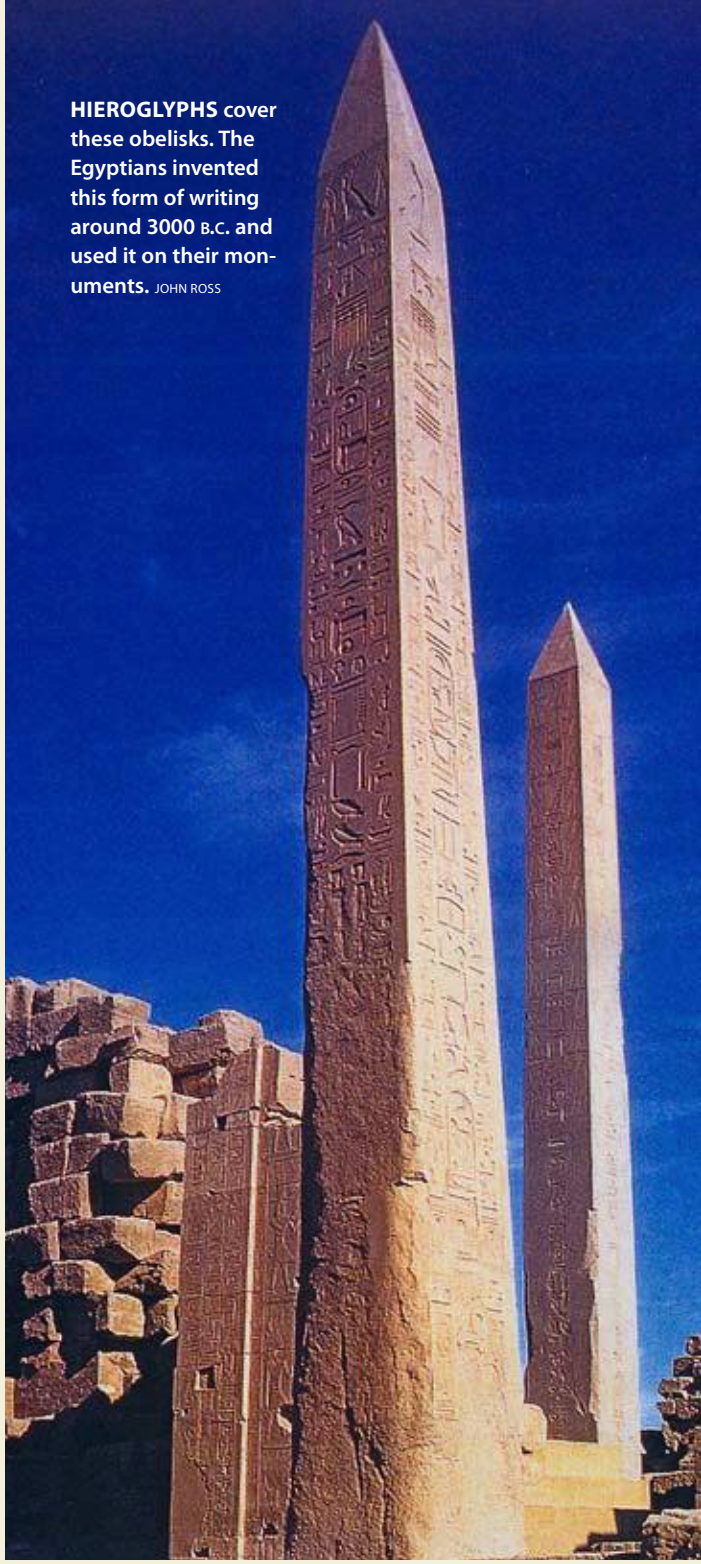
Associated with the *akhet* was "Lightland," a luminous hill of light depicted in ancient Egyptian art and lying within the region of the *akhet*. According to New York University Egyptologist Ogden Goelet, Lightland likely represented twilight, as seen both before sunrise and after sunset.

Most Egyptologists think the symbolic principles underlying the

EGYPTIAN CIVILIZATION arose along the life-giving waters of the Nile River. *ASTRONOMY*: JAY SMITH

Patricia Blackwell Gary *is an Egyptologist at New York University.* **Richard Talcott** *is a senior editor of* Astronomy.

GODDESSES ISIS AND NEPHTHYS, who participated in Egyptian ceremonies of the dead, bless a blue heart scarab. This piece probably originated in Memphis during the 19th dynasty (about 1320–1190 B.C.). BRITISH MUSEUM



HIEROGLYPHS cover these obelisks. The Egyptians invented this form of writing around 3000 B.C. and used it on their monuments. JOHN ROSS

mythological and architectural aspects of the *akhet* pertain almost exclusively to the points along the horizon where the Sun rises and sets. In looking at this from an archaeoastronomy perspective, however, we suggest that while the Sun's appearance and disappearance were the central acts, dramatic opening and closing scenes added to the reverence Egyptians held for these sky regions.

Egyptian icon

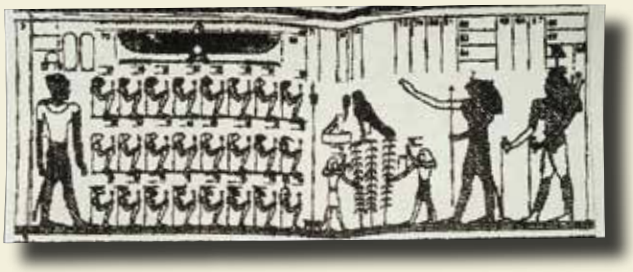
The pyramids represent the epitome of Egyptian art and architecture, and were certainly seen as symbols of the Sun. The first pyramids were not the fully formed, flat-sided objects we've come to know. Instead, they were step pyramids, built in layers, where the top of one layer was broader than the bottom of the layer above it. Most were constructed during the third dynasty, between about 2650 and 2575 B.C. The style evolved quickly, however, and the three great pyramids at Giza were built during the fourth dynasty. The largest was the burial chamber for the king Khufu, and the two smaller ones belonged to Khafre and Menkaure.

What relationship do the pyramids — and the similarly shaped *benben*, for that matter — have to the Sun's appearance in the sky? Many Egyptologists claim the pyramids' inspiration may have been an atmospheric phenomenon known as crepuscular rays. These rays of sunlight appear to spread out from a point. Intermittent clouds can break sunlight into separate beams of light, and perspective effects make them appear to fan out from the Sun. (The same effect causes parallel railroad tracks seemingly to converge in the distance.)

Crepuscular rays can occur with the Sun at or just below the horizon, in which case they open upward, or with the Sun higher in the sky, when they can point down. Anyone who has seen a good display of crepuscular rays knows they can mimic a pyramid's shape. But whether that's what motivated the ancient Egyptians, no one can say.

Pyramid of light

We decided to seek other possible explanations. Judging from evidence presented in records at the Edfu temple, the *benben* seems to be linked to the radiance that brought the Sun-god into existence. So, we looked more closely at events taking place near the times of sunrise and sunset.



HIEROGLYPHS TELL THE STORY of an Egyptian falcon-god who dwelled in a thicket of reeds. This scene appears on the Temple of Horus at Edfu in Upper Egypt. TOBY WILKINSON

THE ZODIACAL LIGHT shows a distinct pyramidal shape when seen against a pitch-black sky — conditions that would have been common in the desert air of ancient Egypt. CHRIS SCHUR

CREPUSCULAR RAYS have also been seen as a possible celestial inspiration for the great pyramids. MONTANARI ENRICO

One phenomenon quickly caught our attention. The zodiacal light has the right shape and appears both shortly before morning twilight in the east and just after evening twilight in the west. The light is a beautiful, ethereal glow that rises from the horizon in the shape of a huge pyramid or cone. The soft white light appears widest at the horizon and tapers slowly to a width of only 5° to 10°. Under the best conditions, the zodiacal light reaches halfway to the zenith.

At its most intense, the light shines slightly brighter than the central regions of the Milky Way. However, the zodiacal light appears diffuse, so any haze or background light from the Moon or a nearby city will mask its glow. That's why most people today have never seen it — even avid observers. From the dark desert skies of ancient Egypt, however, the zodiacal light would have been conspicuous.

As its name implies, the zodiacal light tracks along the zodiac, the menagerie of constellations that encompasses the apparent path of the Sun and planets across our sky, also known as the ecliptic. (Any bright planets offer a convenient guide to finding the ecliptic and seeking out the light.) The Egyptians recognized both the ecliptic and the constellations the Sun traversed, so they could have connected the zodiacal light with the Sun's annual track.

The light appears most prominent when the ecliptic makes a steep angle to the horizon. This orients the pyramid's apex higher in the sky and makes the glow easier to see. From the latitude of Egypt, which lies just north of the Tropic of Cancer, the ecliptic typically meets the horizon at a steep angle. Viewing conditions are slightly better on spring evenings and autumn mornings, but the difference doesn't amount to much. (At mid-latitudes, the discrepancy grows greater, and the zodiacal light becomes difficult to see except at the favored times.)

The light may remind you of twilight — the morning vista is sometimes called the "false dawn" — but you usually can tell the difference because the zodiacal light comes to a sharper peak.

The light originates with dust particles in the inner solar system. Some of that dust comes from material ejected from comet nuclei as the Sun's heat sublimates cometary ices. The rest of it derives from the hundreds of thousands of asteroids that inhabit the solar system between the orbits of Mars and Jupiter. Collisions among these rocky objects grind down their surfaces and release lots of fine dust.

Most of the particles have diameters from a few micrometers up to

WORDS OF EGYPT

AKHET — Egyptian for "horizon"; the place where the Sun was reborn each day.

BENBEN — sacred stone with a cone shape; also, a pyramid's capstone or obelisk's tip.

GIZA — site in Lower Egypt; home of the great pyramids.

HELIOPOLIS — site in Lower Egypt; center of the solar cult.

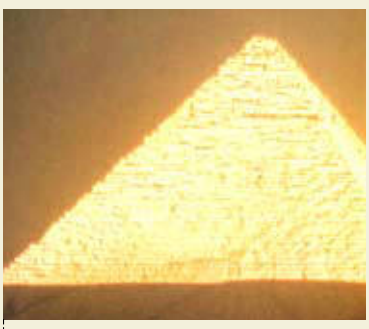
LIGHTLAND — luminous hill of light associated with twilight.

RE — Egyptian sun-god.

SUN PILLAR — vertical shaft of sunlight visible near sunrise or sunset.

ZODIACAL LIGHT — softly glowing pyramid of white light visible before dawn and after dusk.

THE STARS played a huge role in the lives of the ancient Egyptians. Here, a man rides a boat on the Wadi Hammamat (a normally dry riverbed), guided by a bright star. TOBY WILKINSON



WHITE LIMESTONE once covered the pyramids, so they gleamed in sunlight. ILLUSTRATION BY FRED HOLTZ

about a millimeter. The particles remain close to the ecliptic and spiral slowly toward the Sun, where their density and brightness are highest. They glow by reflecting sunlight, a fact the ancient Egyptians surely would have appreciated.

Pillar of light

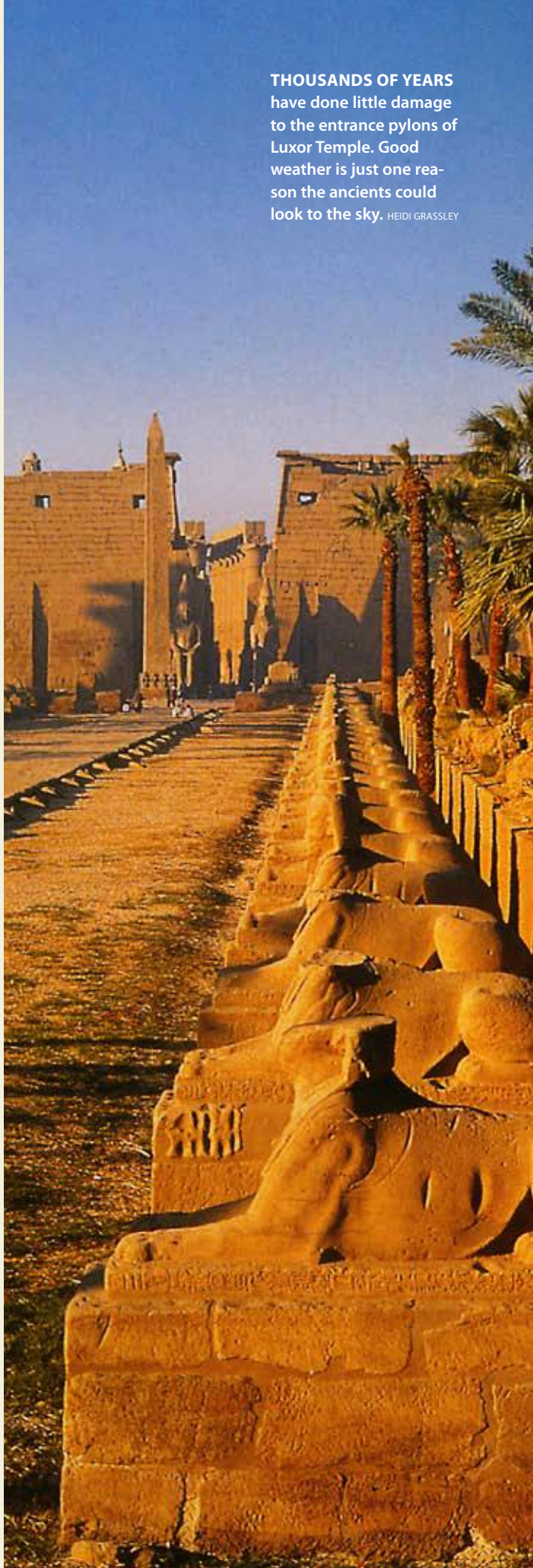
The obelisk's shape also has solar significance. The obelisk represents Egypt's earliest symbolic art and architecture. According to Egyptian mythology, obelisks came in pairs: two in the celestial realm and two on Earth. They were identified as the first manifestation of the primeval god Amun and were thought to correspond to rays of the rising Sun. Traditionally, they were positioned to reflect sunrise and sunset.

Another light show sometimes seen near sunrise or sunset closely matches the obelisk's shape. A Sun pillar is a vertical shaft of light that either rises above or falls below the Sun's position. It usually ends in a point. Occasionally, a pillar will appear both above and below the Sun simultaneously.

Sun pillars arise from sunlight reflecting off the surfaces of six-sided, plate-like ice crystals that make up thin, high-level clouds in Earth's atmosphere. Although they require ice crystals to form, the pillars aren't confined to cold-weather climates. They can appear anywhere around the world because temperatures remain low at the clouds' high altitude.

The Sun played a huge role in how the ancient Egyptians viewed the world and their position in it. The sun-god Re was born each morning when he broke through the eastern horizon. He then traversed the sky to near the zenith before descending to the western horizon. When each day came to end, Re died at dusk, only to be resurrected again when morning twilight returned. It's a story 5,000 years old, but one keeping researchers engaged at the dawn of the 21st century.

ONLINE EXTRA Visit www.astronomy.com/toc to learn about Egyptian observations of Spica.



THOUSANDS OF YEARS have done little damage to the entrance pylons of Luxor Temple. Good weather is just one reason the ancients could look to the sky. HEIDI GRASSLEY

astronomics™ . . . our 27th year.

We've been helping people choose the right telescope since 1979. We have the experience (a staff total of over 150 years of experience using and selling telescopes) to help *you* pick the telescope that fits your needs (and your budget). And, with our seven-figure inventory, we can usually ship you the right scope, right away, from the hundreds of scopes we stock.

We started ***astronomics*** over 26 years ago because we loved astronomy,

Two apos, and one so good you might think it *is* an apo.

The **Astronomy Technologies AT66** has an ED (Extra-low Dispersion glass) doublet lens that Astro-Tech says gives it apochromatic (color-free) images.

We won't go quite that far, but we will say that the $329 66mm ED **Astro-Tech AT66** fully-multicoated f/6 doublets are so sharp, contrasty, and color-free that you'll swear Astro-Tech is right and they really *are* apos.

Left to right: Astro-Tech AT66, $329; AT80, $379; AT80ED, $529

One customer said the only color he could see was on the *outside* of the tube. That's because you don't have to settle for an ordinary plain black optical tube to get great optics. Express your AT66 individuality with a striking chrome, red, blue, burnt orange, white, green, *or* black tube.

The **Astronomy Technologies AT80** is a $379 80mm f/6 achromatic doublet system that well-known refractor designer Thomas M. Back said had "no coma, astigmatism, or zones, and the spherical correction was well beyond the diffraction limit." This optically exceptional and affordable achromat comes in white or blue.

The **AT80ED** has an ED (Extra-low Dispersion glass) 80mm f/6.8 doublet lens for apochromatic (color-free) images.

We think the performance of the **Astro-Tech AT80ED** equals that of other doublet and triplet apos costing hundreds of dollars more than its modest $529 price. To us, equal performance at a big savings makes this fully multicoated 80mm ED scope a bargain indeed. The **AT80ED** is available in blue or black.

Every Astro-Tech has premium features, like dual speed focusing (standard speed and an 11:1 ratio fine focus), a Crayford-style focuser that rotates 360° to the most comfortable viewing angle, and non-marring compression ring eyepiece holder(s), plus a retractable lens shade, dust caps, and carrying case.

Truly sensational optics at affordable prices; each with premium features; and your choice of colors. What's not to like?

A Telegizmos protects your scope day and night.

A **Telegizmos** scope cover protects your telescope from sun and dew. NASA-developed to insulate spacecraft, these aluminized covers are strong, light, and more durable than Mylar. Prices start at only $29.

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Celestron – ED refractor go-to made easy.

80mm Celestron C80 ED R-GT refractor
$1099

You won't spend all of your time hunting for sharp images of celestial wonders with a **Celestron Advanced Series** computerized ED doublet refractor.

A few touches on the NexStar computer hand control and your refractor speeds to any of 45,000 different stars, planets, and deep space objects. Then it will track it for as long as you want to observe through the sharp, contrasty, and virtually color-free ED glass optics.

Each has an adjustable height steel leg tripod, dual battery-operated motor drives, finderscope, eyepiece, and NexStar computer. Here are the ED versions:

80mm (3.1") **C80 ED R-GT** ..... **$1099**[00]
102mm (4") **C100 ED R-GT** ..... **1574**[00]

There's also a big 6" non-ED achromatic go-to scope available:

150mm (6") **C6 R-GT** ..... **$1069**[00]

If you're a traditionalist and prefer a German equatorial mount without go-to, these Advanced Series scopes have adjustable height steel leg tripods, manual slow motion controls (motor drives are optional), finderscope, and eyepiece:

80mm (3.1") **C80 ED R** ..... **$799**[00]
102mm (4") **C100 ED R** ..... **1299**[00]
150mm (6") **C6 R** ..... **849**[00]

A better diagonal makes any scope better.
Astro-Tech *dielectric* diagonals from $69.95 *are* better.

A really good star diagonal increases light transmission *and* improves planetary contrast and detail when compared with the so-so prism diagonal supplied with most scopes.

Astro-Tech diagonals *are* really good diagonals. You can choose either 96% reflectivity enhanced aluminum or durable 99% reflectivity *46-layer* dielectric first surface mirror coatings. Each has a non-marring brass compression ring to hold eyepieces in place. The 2" diagonals come with a 1.25" eyepiece adapter with a compression ring eyepiece holder at no extra charge. The 2" diagonals are available with your choice of a standard 2" barrel to use in a refractor or with a threaded ring that connects to a Schmidt-Cassegrain rear cell.

Here are the five top-quality **Astro-Tech** star diagonals that we stock:

1.25" dielectric **$69.95**
2" enhanced aluminum **79.95**
2" dielectric **89.95**
2" SCT enhanced aluminum **139.95**
2" SCT dielectric **149.95**

Want your TeleVue right now? Look no further.

NP-101 **$3685**
TV-60 **$825**

When you want a TeleVue, you want it right now. You don't want to wait until a dealer gets around to ordering it.

You rarely have to wait to get your TeleVue from ***astronomics****, because we keep a six-figure TeleVue inventory in stock.*

For example, here are a few of the TeleVue eyepieces we can ship today.

8, 11, or 15mm 1.25" Plössl ..... **$85**[00]
32 or 40mm 1.25" Plössl ..... **118**[00]
3, 4, 5, 6, 8, 10, 12, 14, or 18mm 1.25" Radian ..... **250**[00]
2.5, 3.5, 5, 7, 9, 11, or 13mm 1.25" Nagler Type 6 ..... **290**[00]

Here are a few of the TeleVue basic refractor optical tubes that we stock.

TV-60, 2.4" f/6 apo ..... **$825**[00]
TV-76, 3" f/6.3 apo ..... **1320**[00]
TV-85, 3.35" f/7 apo ..... **1750**[00]
TV-102, 4" f/8.6 apo ..... **2250**[00]

These in-stock TeleVue refractors (for use on your own mount) have a diagonal, eyepiece, tube ring, dust covers, and case.

TV-76, 3" f/6.3 apo ..... **$1725**[00]
TV-85, 3.35" f/7 apo ..... **2150**[00]
TV-102, 4" f/8.6 apo ..... **2685**[00]
Renaissance, 4" f/8.6 brass ..... **3250**[00]
NP-101, 4" f/5.4 Petzval apo ..... **3685**[00]

No matter whether it's a telecope or an accessory, if it's from TeleVue, chances are good we have it in stock.

A Meade Ritchey-Chrétien for only $2499? *Fantastique!*

Meade 8" f/10 LX200R Ritchey-Chrétien
$2499
freight paid

At least we think French optician Henri Chrétien would call it "fantastic" if he were still alive and knew that the kind of telescope optics that he and George Ritchey designed in 1930 – the kind used in the 300" Keck telescopes and the Hubble Space Telescope – were available at prices virtually every backyard astronomer and astrophotographer can afford.

The new **Meade LX200R** telescopes use f/10 versions of the modified Ritchey-Chrétien optics used in Meade's famous RCX400 scopes. They are mounted in the proven mechanics of the best-selling Meade LX200GPS series. The result is genuine state-of-the-art telescopes at prices that are within reach and reason.

The 8" to14" LX200R scopes usually ship from our stock, saving you time over non-stocking dealers who must have Meade ship them to you (and if you live in California, we save you the sales tax).

Here are the *freight-paid* prices on the LX200R scopes that we ship from our stock:

8" **LX200R** ..... **$2499**[00]
8" **LX200R,** with UHTC optics ..... **2674**[00]
10" **LX200R** ..... **3399**[00]
10" **LX200R,** with UHTC optics ..... **3634**[00]
12" **LX200R** ..... **4399**[00]
12" **LX200R,** with UHTC optics ..... **4694**[00]
14" **LX200R** ..... **5999**[00]
14" **LX200R,** with UHTC optics ..... **6349**[00]

Because of their weight, these 16" LX200R scopes ship to you via truck from Meade.

16" **LX200R,** without mount, w/UHTC ... **11,529**[00]
16" **LX200R,** tripod, w/UHTC ..... **12,494**[00]
16" **LX200R,** altaz pier, w/UHTC ..... **12,524**[00]
16" **LX200R,** eq pier, w/UHTC ..... **12,779**[00]

Outer space is infinite. Your car's back seat is not.

Meade 10" f/5 standard LightBridge
$649

Meade LightBridge Dobsonians use a truss-tube design that lets even the big 12" models break down into a few small packages that easily fit into a compact car. One person can transport even the largest Meade LightBridge to a dark sky site and set it up on their own.

All Meade LightBridge Dobs have a 2" machined aluminum Crayford-style focuser with a 1.25" eyepiece adapter. A battery-operated fan on the metal primary mirror cell assures fast cooling of the diffraction-limited BK7 optical glass mirror. No tools are needed to assemble and break down the scope in the field.

Standard models have a 1.25" 26mm Super Plössl eyepiece, a red dot finder, and Teflon bearings. Deluxe models have a 2" 26mm 70° field QX eyepiece, an illuminated finder with four different reticle patterns, and roller bearings for smooth hitch-free motion at the touch of a finger.

The prices below include the shipping from the Meade factory.

8" f/6 standard LightBridge ..... **$469**[00]
8" f/6 deluxe LightBridge ..... **569**[00]
10" f/5 standard LightBridge ..... **649**[00]
10" f/5 deluxe LightBridge ..... **749**[00]
12" f/5 standard LightBridge ..... **949**[00]
12" f/5 deluxe LightBridge ..... **1049**[00]

Celestron *SkyAlign* go-to scopes start at a low $279.

80mm Celestron NexStar 80 SLT

You don't need to know the Pleiades from Polaris to find your way around the sky with a **Celestron SLT** go-to scope. With Celestron *SkyAlign* technology, just point your SLT at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet), and the SLT will find the planets and over 4,000 deep space objects for you *automatically.* A few anonymous points of light are all you need to find your way around the skies.

Celestron SLT no-guesswork go-to scopes are available in these sizes:

NexStar 60, 60mm refractor ..... **$279**[00]
NexStar 80, 80mm refractor ..... **379**[00]
NexStar 102, 102mm refractor ..... **479**[00]
NexStar 114, 114mm reflector ..... **399**[00]
NexStar 130, 130mm reflector ..... **439**[00]

Each has *two* eyepieces, red dot finder, motor drives, stainless steel tripod, NexStar computer, software to control the scope from your computer, and more.

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Our 27th year of friendly service, good advice, and money-saving prices.

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Toll-free from the 50 United States and Canada.

Anyone can sell you a telescope. We'll sell you the right telescope.™

not just as a business. Our sales may have grown over a thousand-fold since that first year, but we're still the same family-owned, family-run, full-line telescope dealer we were in 1979. And we still love astronomy.

21st century Celestron go-to . . . at a 1984 price.

If you fondly remember the original orange-tube Celestron C8 – the scope that made amateur astronomy affordable – the **Celestron NexStar 8i Special Edition** will bring back the good old days . . . at a low price straight out of the 1980s!

The scope has a modern anodized version of Celestron's vintage orange and black paint, a convenient go-to computer with no-guesswork *SkyAlign* technology, and the bright images of Celestron's best Starbright XLT multicoatings.

The most amazing part? This 21st century telescope is available for less than the price of a C8 from 1984 that didn't even have a computer.

Amateur astronomy has changed a lot over the past 20 years. But a Celestron's value and performance are standards you've been able to rely on – *always!*

$1399

Celestron 8" f/10 N8iSE

Serious solar observing for the price of an eyepiece!

$499

For less than cost of some premium eyepieces, the sub-Ångstrom hydrogen alpha filter in the **Coronado PST** (Personal Solar Telescope) lets you see the ever-changing drama of solar flares and prominences growing and subsiding before your eyes. It doesn't just show you sunspots, as do ordinary solar filters.

The PST includes a dedicated 60mm refractor, built-in solar filter, a safe built-in Sun finder, and an eyepiece.

Meade ED triplet apo refractors start at $599. Wow!

Meade Series 5000 ED refractors use ED (Extra-low Dispersion) glass in their fully multicoated, air-spaced, triplet apochromatic optical systems. The ED glass provides extra high contrast, with no false color fringing around bright objects. It makes these refractors superb for wide field astrophotography, as well as exceptional for visual observing.

These are optical tubes only, with no mounts. They have adjustable lens cells, Crayford-style focuser, dust covers, L-bracket tripod mount, retractable lens shade, and a hard case.

There are also package versions available that add a $199 retail 2" dielectric star diagonal for only $100.

$699

80mm ED APO package

80mm ED, 3.1" f/6 triplet apo ..... **$599**^{00}

80mm ED, as above, w/2" dielectric diag .... **699**^{00}

127mm ED, 5" f/7.5 triplet apo ..... **1799**^{00}

127mm ED, as above, w/2" dielectric diag .. **1899**^{00}

> As always, it has been a real pleasure talking with you on the phone. Your politeness and willingness to make sure I am a happy customer is the reason why I continue to do all of my business with your firm.
>
> **Customer Quote of the Month #171**

Celestron NexImage captures the solar system for $99.

The $99 **Celestron NexImage** CCD camera takes high power full color images of the Moon and planets with any telescope. It sends them to your computer to view live or print out later. The full color CCD imaging chip in the NexImage has a big 640 x 480 array of 5.4 micron pixels for sharp and clear high-resolution images.

For wider lunar panoramas, the optional $24.50 NexImage Reducer Lens will double the camera's field of view.

A 6 year-old can move your telescope.

The **ScopeBuggy** scope transporter's 10" pneumatic tires, pivoting front wheel, and pull handle are so efficient that one customer's 6 year-old can move his 14" SCT all by herself.

$265

Celestron Dobs are nifty, inexpensive, *and in stock.*

Celestron StarHopper Dobsonians use roller bearings for smooth hitch-free motion at the touch of a finger.

The 6" StarHopper comes with a 6 x 30mm finder, a 1.25" metal rack and pinion focuser, and a 25mm 1.25" Plössl eyepiece.

8", 10", and 12" StarHoppers have a big 9 x 50mm finder, 2" metal rack and pinion focuser (with a 1.25" eyepiece adapter), and a 32mm E-Lux 2" eyepiece. The 10" and 12" scopes have a battery-operated fan for cooling their primary mirrors. All scopes have fast cool-down metal tubes and BK7 optical glass mirrors, and all are in stock for immediate shipment.

8" f/6 StarHopper

$349

Here are the prices for the fully-equipped Celestron StarHopper Dobsonians we stock.

6" f/8 StarHopper ..... **$249**^{00} + $59 freight

8" f/6 StarHopper ..... **339**^{00} + $69 freight

10" f/5 StarHopper ..... **499**^{00} + $79 freight

12" f/5 StarHopper ..... **849**^{00} + $129 freight

12 volt power to the people!

You can recharge a **Celestron Power Tank** battery many times, saving you the cost of buying flashlight batteries every few weeks to power your scope. 7 amp hour Power Tanks start at only **$59.95**.

astronomics. No hard sell. No guesswork. Just honest advice, the time to make sure you get the right telescope and accessories, and a good price. Call us toll free at (800) 422-7876 and find out for yourself.

Celestron's SkyScout *tells* you about the sky while it shows you the night's sights.

$399

The **Celestron SkyScout** is an award-winning handheld non-magnifying GPS-based personal planetarium that identifies or locates more than 6,000 celestial objects visible to the unaided eye, then tells you their facts and history. Use the SkyScout by itself to learn the legends, myths, and sights of the sky. Or mount it on your telescope to let it guide you from one celestial showpiece to another.

There's a scrolling 5-line display of text and graphics. Supplied earphones let you hear the commentary so you don't have to look away from the sky to read it. Optional speakers let others hear, too.

The SkyScout transforms the night sky into a planetarium for stargazers, families, and students. It makes learning the stories of the sky – *and finding your way around the sky* – easier than ever before.

No-guesswork Celestron *GPS* Schmidt-Cassegrains.

Celestron 8" f/10 CPC800

$1899

It's easy to find your way around the sky with a **Celestron CPC**. Just point it at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet or the Moon), and the CPC will find over 45,000 deep space objects for you at the touch of a button.

You don't have to memorize a star chart to use a CPC. The scope's GPS system and a few anonymous lights in the sky are all you need.

Celestron CPC Schmidt-Cassegrains are fully equipped with all the features you need to start observing immediately.

8" **CPC800**, Starbright multicoatings ... **$1899**^{00}

8" **CPC800X**, XLT multicoatings ..... **1999**^{00}

9¼" **CPC925**, Starbright multicoatings .. **2349**^{00}

9¼" **CPC925X**, XLT multicoatings ..... **2499**^{00}

11" **CPC1100**, Starbright multicoatings . **2599**^{00}

11" **CPC1100X**, XLT multicoatings ..... **2799**^{00}

Big binoculars. Bright images. Little prices.

$329

You don't need a telescope to enjoy astronomy. Nebulas, galaxies, and star clusters are all visible through large aperture binoculars, as are myriad craters, seas, and mountains on the Moon.

The big $329 **25 x 100mm Celestron Skymaster**, shown, gathers as much light as two 4" scopes, one for each eye.

The smaller but similar **20 x 80mm Celestron Skymaster**, not shown, is only $239. Both are protected by Celestron's *Lifetime No-Fault Limited Warranty.*

Are these great values? You bet they are.

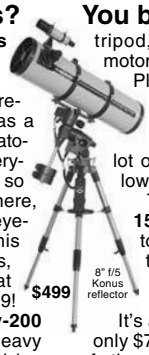
The low prices of these **Konus** telescopes are downright amazing.

Consider the optically very nice 90mm **Konusmotor-90** f/11 refractor, to the left. It has a good-quality equatorial mount, a battery-powered motor drive so you can use it anywhere, and *two* 1.25" Plössl eyepieces. We sell this scope by the dozens, because it's a great value at only $209!

$209

3.5" f/11 Konus refractor

The **Konusky-200** 8" f/5 reflector, above right, has a heavy duty equatorial mount with a steel leg tripod, *dual-axis* DC motor drives, *two* 1.25" Plössl eyepieces, an 8 x 50mm finderscope, and polar axis finder. It's a lot of telescope for the low price of only $499!



$499

8" f/5 Konus reflector

The **Motormax-150** 6" Maksutov, to the right, has the same heavy duty mount and accessories as the 8" reflector.

6" f/12 Konus Maksutov

$799

It's a terrific value at its low price of only $799, which is well below the cost of other large Maksutovs.

A go-to scope only $209.95?

Go-to scopes take the guesswork out of finding your way around the skies. They move your scope *automatically* to the object you want to see, so you can find your way around the skies like a pro.

The **Bushnell NorthStar 3** 3" go-to reflector has everything you need to get started in astronomy, including *two* eyepieces, Barlow, red dot finder, and talking computer with 20,000 stars and objects to locate for you. Want a great value in a go-to starter scope? Look no further.

$209.95

Bushnell NorthStar 3" go-to reflector

Hard to believe. BUSHNELL

The new Meade Deep Sky Imager *II,* $599.

The new **Meade Deep Sky Imager II** has a larger CCD chip than the original Deep Sky Imager (which is still available at $299). The DSI II has greater sensitivity, higher resolution (752 x 582 pixels), and dramatically lower thermal noise that lets you take long deep space exposures without having to cool the camera.

While the new DSI II works with any scope, you can use its NASA-developed "Drizzle" software with Meade Autostar-equipped ETX, LX90, LX200, or RCX400 telescopes for long exposures without the need for an equatorial wedge.

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ASK ASTRO

Astronomy's editors and experts from around the globe answer your questions about the cosmos. This month: satellite altitudes, does the galaxy control star spin, and can planets share orbits?

HOW HIGH IS HUBBLE?

Q: What's the altitude of a typical artificial satellite, and how can I see one?

— **BILL PATTON,** PHILOMATH, OREGON

A: There's no such thing as a typical artificial satellite, so there is no single altitude. Satellites have different purposes — communications, Earth observation, astronomy, and navigation, for example — that drive how high they'll orbit.

Satellites broadcasting TV signals are located about 22,240 miles (35,800 kilometers) above sea level in geostationary Earth orbits (GEO). Positioned above Earth's equator, geostationary satellites complete one revolution in exactly a day, so they seem to hover over the same longitude. You'll always receive your TV signal because the satellite never disappears below your horizon.

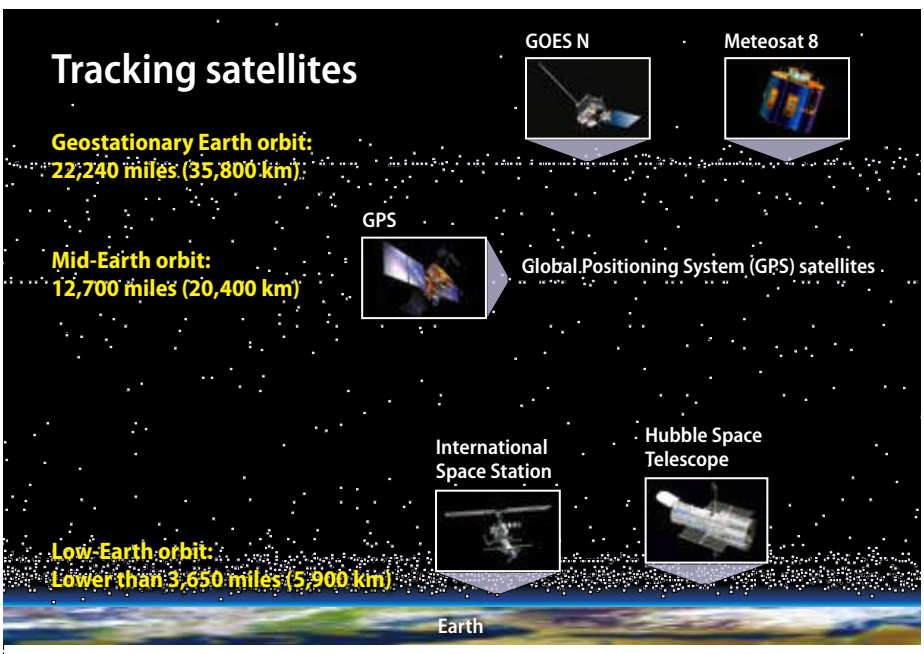
Mid-Earth orbit (MEO) is one in which a satellite completes a single revolution every 12 hours. MEO satellites orbit at altitudes around 12,700 miles (20,400 km). Global Positioning System (GPS) satellites populate this region.

Satellites in low-Earth orbit (LEO) have altitudes lower than 3,650 miles (5,900 km) above sea level. These satellites move quickly, taking less than 4 hours to complete an orbit. Well-known objects in LEO include the Hubble Space Telescope (altitude 380 miles [610 km]) and the International Space Station, which orbits 245 miles (400 km) up.

Satellites for observing Earth use a special orbit referred to as a Sun-synchronous LEO. The properties of these orbits enable a satellite to view Earth with the Sun in exactly the same position day after day. Satellites like NASA's Landsat series monitor environmental changes — for example, vegetation growth. For these observations to be meaningful, each image must have the same illumination. Such orbits are also great for surveillance satellites, as one can select lighting conditions best suited for a given target.

You can see Earth-orbiting satellites if they're above your horizon when the Sun is below it. Hundreds of miles up, a satellite can be in sunlight for a couple of hours after sunset (or before sunrise) as seen from the ground. Other important factors affect a satellite's visibility, such as its size and how close it passes to your location.

Unfortunately, satellite orbits change with time, and this means the mathematics needed to determine when you can see a given satellite goes far beyond simple geometry. You'll need a computer to calculate which satellites are potentially visible from your location on a given day. QuickSat (available on the Internet at users2.ev1.net/~mmccants/programs) is one of many programs available for this purpose. Web-based applications like Heavens Above (www.heavens-above.com) or NASA's J-Track (science.nasa.gov/Realtime/jtrack) will do the job as well. — **BILL COOKE,** NASA/MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA



SATELLITES use different orbits determined by their intended use. Each dot represents one of the thousands of satellites now in orbit. *ASTRONOMY:* ROEN KELLY, AFTER J. RICHARD GOTT AND MARIO JURIĆ

GALACTIC ALIGNMENT

Q: Do the stars in the Milky Way spin in a way that aligns with the galactic equator?

— **TIMOTHY D. BOYLE,** TSUKUBA SCIENCE CITY, JAPAN

A: Most planets in our solar system have spin axes inclined close to 90° to the ecliptic, the plane of Earth's orbit around the Sun. There are exceptions: Uranus rotates on an axis in line with the ecliptic, and Venus' axis tips 177° (because astronomers define a planet's north pole based on its spin

direction, and Venus rotates opposite the direction of most planets). But the alignment of other planets is close enough that it can't be considered a coincidence.

Similarly, you might expect that stars' rotational poles would be aligned with the Milky Way's spin axis. But the North Galactic Pole is located in Coma Berenices, 70° from the North Ecliptic Pole in Draco. Is the Sun the galaxy's odd star out, like Uranus and Venus in the solar system? Or do stellar spin axes fail to line up with the galaxy's rotation?

Stars form in giant molecular clouds — huge conglomerations of cold, dense gas in the Milky Way's spiral arms. Molecular clouds form and dissipate in less time than it takes them to orbit the galaxy, so they never really "feel" its rotation.

The gas in giant molecular clouds is turbulent, with eddies flowing randomly throughout the cloud. Star formation begins when part of a cloud becomes dense enough that gravity pulls the gas inward. Turbulence gives this collapsing fragment some spin. The cloud's swirling eddies can move in any direction, so, cloud fragments may spin in any orientation. One molecular cloud can form thousands of stars, each with a random rotation axis.

As the material collapses, the cloud's rotation becomes more prominent, just as spinning figure skaters speed up by pulling their arms inward. Soon, the gas collapses to form a disk the size of our solar system with a central protostar. Everything will be spinning in the same direction as the turbulent knot from which the system formed. All the gas orbits the central star in the same direction, so anything that forms from it — such as planets — will naturally spin the same way.

IN THE KNOW

ORBITAL ANGULAR MOMENTUM
This important physical quantity comes from the mass, speed, and distance of an orbiting body. Changing a moon's orbital distance raises or lowers its orbital speed in much the same way as altering body position changes a spinning figure skater's rotation.

NASA/M. J. McCAUGHREAN/C. R. O'DELL

THE HUBBLE Space Telescope imaged protoplanetary disks around young stars in the Orion Nebula. The visible disks tilt at different angles. This is expected if the molecular cloud in which they formed churned with turbulence.

In this simple picture, planets should have their spin axes aligned with their parent stars'. And stars, even those forming from the same molecular cloud, should have randomly oriented spin axes. But is this what astronomers see?

In 2001, Helmut Abt of Arizona's Kitt Peak National Observatory published a study of spotted stars. The spots are much larger than sunspots, so we can actually see the amount of starlight change as spots rotate into and out of view. Abt used this information to determine the angle of the stars' rotational axis with respect to the Sun. **The spin axes are completely random,** thanks to small amounts of turbulence in a long-vanished cloud. — **KURTIS WILLIAMS,** STEWARD OBSERVATORY, TUCSON, ARIZONA

ORBIT-SHARING PLANETS

Q: Is it possible for two planets to share the same orbit?
— **COURTNEY EVANS,** IRVINGTON, NEW JERSEY

A: It's possible for two objects to share similar orbits, but not the exact same orbit. Saturn's moons Janus and Epimetheus run on orbits that differ in size by only 30 miles (50 km). This similarity results in a surprising interaction: The two moons swap orbits every 4 years.

Until fall 2005, Epimetheus orbited on the inside track and, because it was closer to Saturn, the moon traveled faster than Janus. As the distance between the moons decreased, Epimetheus pulled on Janus from behind just as Janus tugged Epimetheus. This interaction caused the moons to exchange angular momentum. Epimetheus gained momentum, moved out from Saturn slightly, and moved slower in its orbit, while Janus lost momentum, dropped toward Saturn, and sped up.

The moons' latest orbital swap, which takes about 100 days to complete, concluded in late January. Their orbits are stable because resonant effects from the gravity of Saturn and its other moons force the issue and lock the "co-orbital moons" into these paths.

About 1,800 asteroids share Jupiter's orbit. They lead and follow the giant planet by 60°. So, a pair of planets could develop a similar relationship, especially if, like Jupiter and its swarm of asteroids, one object were many times more massive than the other.

It's unclear how stable such configurations can be, especially if other massive planets orbit the star. Their gravitational influence could eventually upset the delicate balance, and the planets would go their separate ways. — **FRANCIS REDDY,** ASSOCIATE EDITOR

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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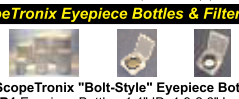

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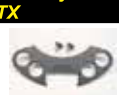

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Sure they're all round, but each globular cluster offers a different view through a telescope. /// BY STEVE COE

Tour summer's great globulars

In the deep-sky menagerie, nothing excites new observers more than globular star clusters. It's easy to see why. Many shine brightly enough to be seen even from urban settings. But when observed from a dark site, these objects explode with detail. Astronomers classify two star-cluster types: open and globular. Open ones lie within our galaxy's spiral arms. You'll see them along the glowing path of the Milky Way. The richest open star clusters contain hundreds of young stars.

Globular clusters appear as spheres of stars that took their shape when the Milky Way formed, 13 billion years ago. The largest globulars contain a million or so stars and measure about 300 light-years across.

Globular clusters also differ from open clusters because globulars lie in a region outside the Milky Way's disk called the galactic halo. Open clusters move with the arms of the Milky Way while globulars lie some distance above or below our galaxy's plane. Some of the most prominent globulars are found a short distance from the Milky Way's centerline, where the dust does not dim this distant starlight.

M75 in Sagittarius lies well beyond the Milky Way's center. Because of its distance, M75 looks compact and highly concentrated. Astronomers estimate this cluster contains nearly 200,000 stars. KEN SIARKIEWICZ/ADAM BLOCK/NOAO/AURA/NSF

TARGET THESE SUMMER GLOBULARS

Object	R.A.	Dec.	Mag.
M4	16h24m	–26°32'	5.6
NGC 6144	16h27m	–26°01'	9.1
M10	16h57m	–4°06'	6.6
NGC 6284	17h05m	–24°46'	8.8
NGC 6325	17h18m	–23°46'	10.7
M28	18h25m	–24°52'	6.8
NGC 6642	18h32m	–23°29'	9.1
M22	18h36m	–23°54'	5.1

This list gives the positions and magnitudes of the clusters discussed in the story. To locate these objects, use the chart on page 75. R.A. = Right ascension; Dec. = Declination; Mag. = Visual magnitude

Because globular clusters orbit the Milky Way's center, deep-sky observers will see the most globulars when they look there. The constellations Sagittarius, Scorpius, and Ophiuchus are packed with them.

Globular clusters represent one class of celestial object on which you can improve your observing skills and telescope use, regardless of the scope's aperture.

Two features to look for are dark markings within the cluster and long, curving chains of stars. And note if you detect any color in the cluster stars. Don't just "take a peek." Spend some time at the eyepiece and take in the view.

In the Scorpion

If you're just starting out observing globulars, stick to bright ones. **M4** lies near the bright red giant star Antares (Alpha [α] Scorpii). If it's dark enough to show Scorpius' entire fish-hook shape, then a finder scope or binoculars will show this globular cluster in the same field of view with

Steve Coe *is a member of Phoenix's Saguaro Astronomy Club. His book,* Observing Nebulae, *will be published by Springer-Verlag this year.*

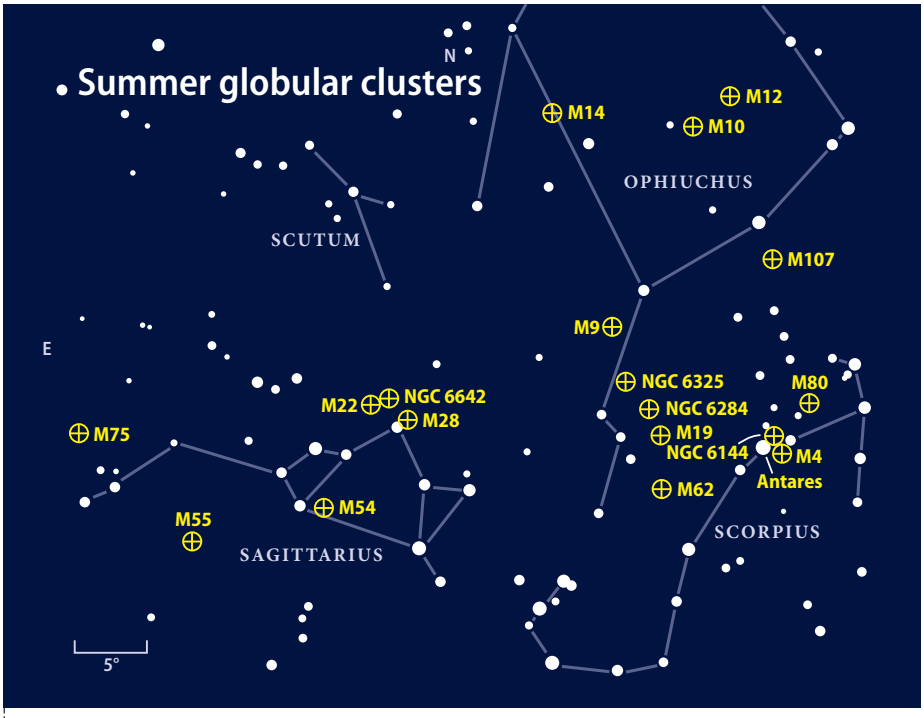
M4 sits 1.3° west of Antares (Alpha [α] Scorpii). From a dark site, you'll see M4 easily without optical aid. Through a 6-inch or larger telescope, this cluster shows lots of detail. GEORGE SEITZ/ADAM BLOCK/NOAO/AURA/NSF

Antares. And under the darkest sky, sharp-eyed observers can see M4 without optics.

Through a 6-inch scope at 65x, M4 appears bright, large, and irregularly round. Look for a central "bar" feature and a bright lane of stars across the cluster's middle. Averted vision (looking slightly away from a faint object) resolves more stars that "fill in" this glowing globe. At 105x, I counted 33 individual stars.

Through an 11-inch scope at 200x, this beautiful cluster appeared brighter in the middle, and I resolved 48 stars. The outer sections show several delicate chains of stars that curve out and away from M4 to meld into the Milky Way nearby.

Next, try for a less-famous globular near Antares. **NGC 6144** is faint, small, and slightly elongated (I estimate the ratio of its dimensions as 1.2 to 1). Its center is a bit brighter than its outer regions. Through my 11-inch scope at 200x, I resolved only 10 stars. This cluster has a low surface brightness, so it doesn't stand out well from the Milky Way's background glow.



ASTRONOMY: ROEN KELLY

THE CONSTELLATIONS Scorpius the Scorpion, Ophiuchus the Serpent-bearer, and Sagittarius the Archer contain lots of globular clusters because the Milky Way's center lies in this direction. Use this finder chart to locate some of the brightest summer globulars.

M55 IN SAGITTARIUS appears low in the south, so it poses problems for observers in northern latitudes. Look 8° east of magnitude 2.6 Zeta (ζ) Sagittarii for this cluster. M55 appears loose because of its size, nearly two-thirds the Full Moon's diameter. LEE C. COOMBS

DOUG MATTHEWS/ADAM BLOCK/NOAO/AURA/NSF

M22 in Sagittarius ranks as the sky's third-brightest globular cluster behind only Omega Centauri (NGC 5139) and 47 Tucanae (NGC 104). M22 lies 2.5° northeast of Lambda (λ) Sagittarii.

MICHAEL GARIEPY/ADAM BLOCK/NOAO/AURA/NSF

M12 in Ophiuchus looks similar to M10, except for being slightly smaller and a bit fainter. From a dark site, a sharp-eyed observer may glimpse M12 without optical aid.

In the Serpent-bearer

North and east of Scorpius lies Ophiuchus. Let's start there with **M10**, which shines at magnitude 6.6. This cluster is unmistakable in binoculars or a finder scope. A globular nearly as bright, magnitude 6.7, M12, lies 3° northwest of M10.

Through a 13-inch reflector at 150x, M10 looks bright, large, round, much brighter in the middle, and well-resolved. Moving up to 220x shows 110 stars. Look for two prominent lines of stars that extend from the center and loop into chains that curve in opposite directions, like a lawn sprinkler. An 11th-magnitude orange star sits on the cluster's north side. Use averted vision to fill in the cluster.

NGC 6284 shines at magnitude 8.8, is small, round, and has a bright and compressed middle. I've seen it through an 11x80 finder scope. Through my 13-inch, I couldn't resolve it into stars at 100x. When I increased the magnification to 330x, however, I saw 10 stars. Resolution still wasn't easy. Averted vision helped a lot, making the cluster grow in size and resolving a few stars in the core. This globular lies 46,000 light-years away, on the far side of the galaxy from our solar system, so it's tough to resolve individual stars.

NGC 6325 glows feebly at magnitude 10.7. This globular looks faint, large, and somewhat brighter in the middle at 100x through my 13-inch. Few field stars lie in the vicinity of this globular because of nearby dark nebulae. On a great night, I noticed a little elongation (about 1.2 by 1) along a north-south line. I couldn't resolve individual stars at either 220x or 330x.

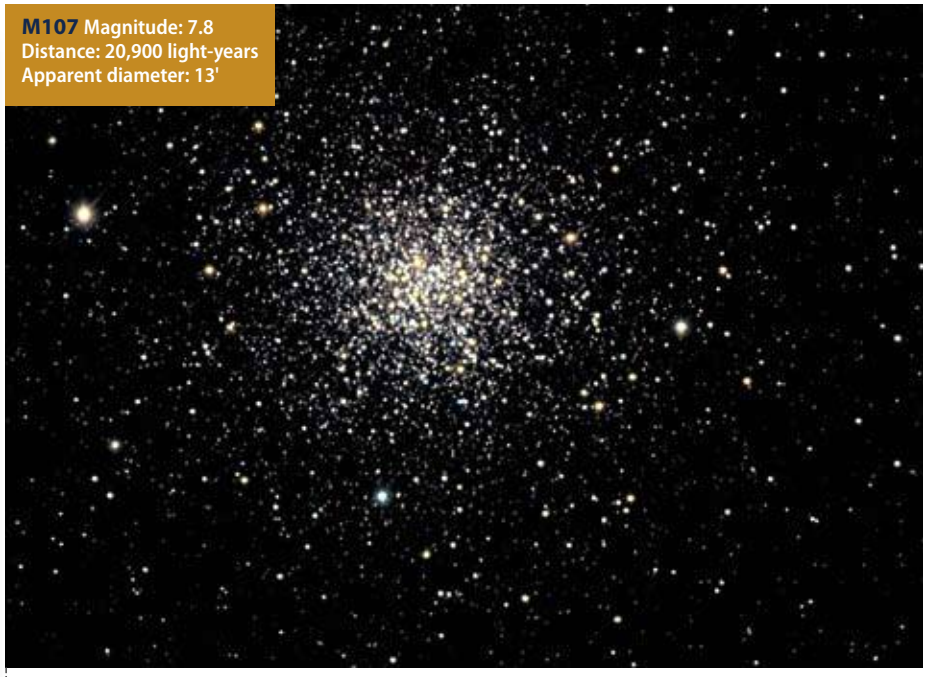
In the Archer

The Milky Way's center lies within the borders of Sagittarius, so let's complete our tour of globular clusters with some examples from the constellation of the Archer.

TEN MORE GLOBULARS YOU'LL ENJOY

Object	R.A.	Dec.	Mag.
M80	16h17m	–22°59'	7.2
M107	16h33m	–13°03'	7.8
M12	16h47m	–1°57'	6.7
M62	17h01m	–30°07'	6.6
M19	17h03m	–26°16'	6.8
M9	17h19m	–18°31'	7.9
M14	17h38m	–3°15'	7.6
M54	18h55m	–30°29'	7.7
M55	19h40m	–30°58'	6.3
M75	20h06m	–21°55'	8.6

In addition to the globular clusters discussed in the text, the author selected ten more that lie in the same area of sky. To locate these objects, use the finder chart on page 75. R.A. = Right ascension; Dec. = Declination; Mag. = Visual magnitude



BRUCE HUGO AND LESLIE GAUL/ADAM BLOCK/NOAO/AURA/NSF

M107 in Ophiuchus lies 2.7° south-southwest of magnitude 2.6 Zeta (ζ) Ophiuchi. M107 contains more than two dozen variable stars and measures roughly 80 light-years across.

MICHAEL AND MICHAEL McGUIGGAN/ADAM BLOCK/NOAO/AURA/NSF

M10 in Ophiuchus lies in an area devoid of bright stars. Find it 10.6° due east of magnitude 2.7 Yed Prior (Delta [δ] Ophiuchi) or 1° west of 5th-magnitude 30 Ophiuchi. Don't confuse M10 with M12, which lies a bit more than 3° northwest of M10.

M28 lies 1° northwest of Kaus Borealis (Lambda [λ] Sagittarii). This magnitude 6.8 cluster is bright, large, round, and has a bright middle. Through a 6-inch scope at 65x, I resolved no stars. Switching to 135x allowed me to resolve five stars consistently; another eight came and went as the seeing changed. With averted vision, I noticed a bizarre effect: As I looked at the cluster's outer edge, different stars across the face of this globular appeared to turn on and off as I accidentally used averted vision on them.

Even from a mediocre observing site, I saw M28 in an 11x80 finder scope. At 100x through the 13-inch Newtonian, this cluster looked large, bright, and round, with increased brightness in the middle. Raising the power to 220x really shows this globular at its best. I resolved 21 stars constantly, and averted vision revealed another 50 or so tiny star points.

NGC 6642 measures roughly 10' across and shines at magnitude 9.1. It appeared large, round, and bright (brightest in the middle) through the 11-inch at 125x. Moving up to 200x helps the resolution. Instead of five stars, I could hold 10 with direct vision and another 20 using averted vision, but they were right at the edge of visibility. This cluster contains numerous faint stars.

I just can't observe summer globulars without spending some time at one of my favorite deep-sky objects, **M22**. It was the first globular discovered (but mistaken for a nebula) and is the third-brightest in the sky. To the unaided eye, through binoculars, or in a finder scope, it's the fuzzy thing not quite 3° east-northeast of M28. Both globulars lie above the top of Sagittarius' "teapot" asterism.

Through a 6-inch scope at 40x, magnitude 5.1 M22 looks brilliant, large, round, and somewhat compressed. At 135x, 47 stars resolved with direct vision, and I saw another 20 or so with averted vision. A prominent chevron of stars lies on the cluster's north side.

Through my 13-inch reflector at 220x, I can resolve 64 stars in the northwest quadrant of M22. That makes the total number of resolvable stars around 250.

Remember, just because all globulars are round doesn't mean they all look the same. Each star cluster offers something different through the telescope. Because these objects lie in the same part of the sky, you can compare and contrast them by moving from one to the next. I hope this short tour gets you started observing this fascinating class of deep-sky objects — there's plenty to see in these beautiful and distant globes of stars.

This guide will help you get the most from observing Jupiter at its best. /// BY MICHAEL E. BAKICH

All hail the king

When Jupiter reaches opposition —

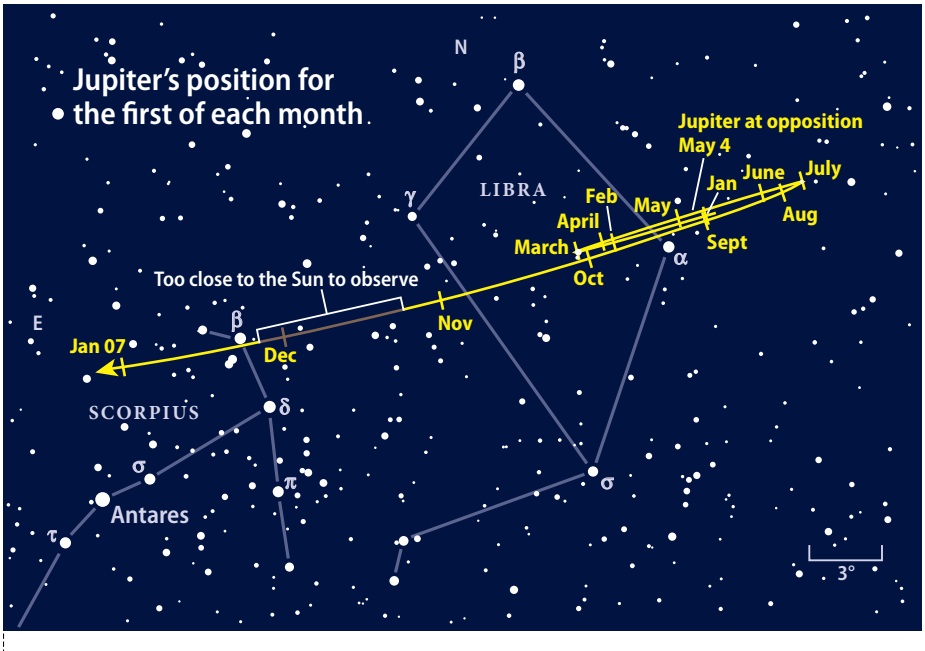
the point in its orbit opposite the Sun from Earth — May 4, it will appear bigger and brighter than at any other time this year. The planet will glare at magnitude –2.5, making it the brightest object in the sky until Venus rises before dawn.

Throughout 2006, the king of planets looms in front of the stars of Libra the Scales. For observers in mid-northern latitudes, this means the planet won't climb high in the sky, where the best views lie. At opposition, Jupiter's altitude maximizes at local midnight, when the planet stands about 40° high in the south. At this time, Jupiter will subtend an angle of 45".

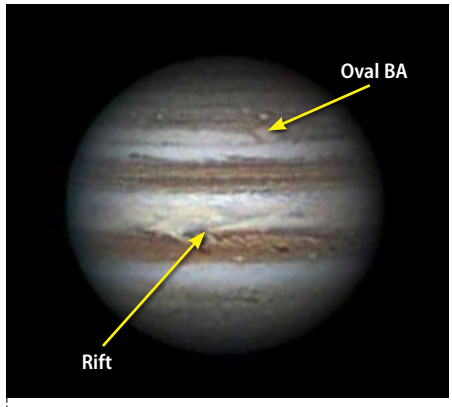
Next to the Moon, Jupiter ranks as the celestial object with the greatest detail. Even small telescopes show the four Galilean satellites, which appear as bright stars on either side of Jupiter. Generally seen in a straight line, these four moons also can assume triangular and other arrangements.

When you focus on the planet, you'll see two dark stripes. These stripes — one above and one below the equator — are the North and South Equatorial Belts. Through larger telescopes and with higher magnification, more belts and zones come into view.

At high magnification, you'll notice the poles appear flattened, a result of Jupiter's rapid rotation rate coupled with the fact that it's not a solid body. Jupiter's equatorial diameter surpasses its polar diameter by more than 5,600 miles (9,000 kilometers).



JUPITER travels among the stars of Libra the Scales in 2006. To find it, simply look for the brightest point of light in the evening sky. *ASTRONOMY:* ROEN KELLY



DAMIAN PEACH

JUPITER'S FEATURES remain the same in an overall sense, but small changes occur all the time. In this image, taken April 24, 2005, note the rift in the North Equatorial Belt and the white oval designated BA in the South Temperate Belt. Oval BA formed when two ovals merged between December 1999 and March 2000.

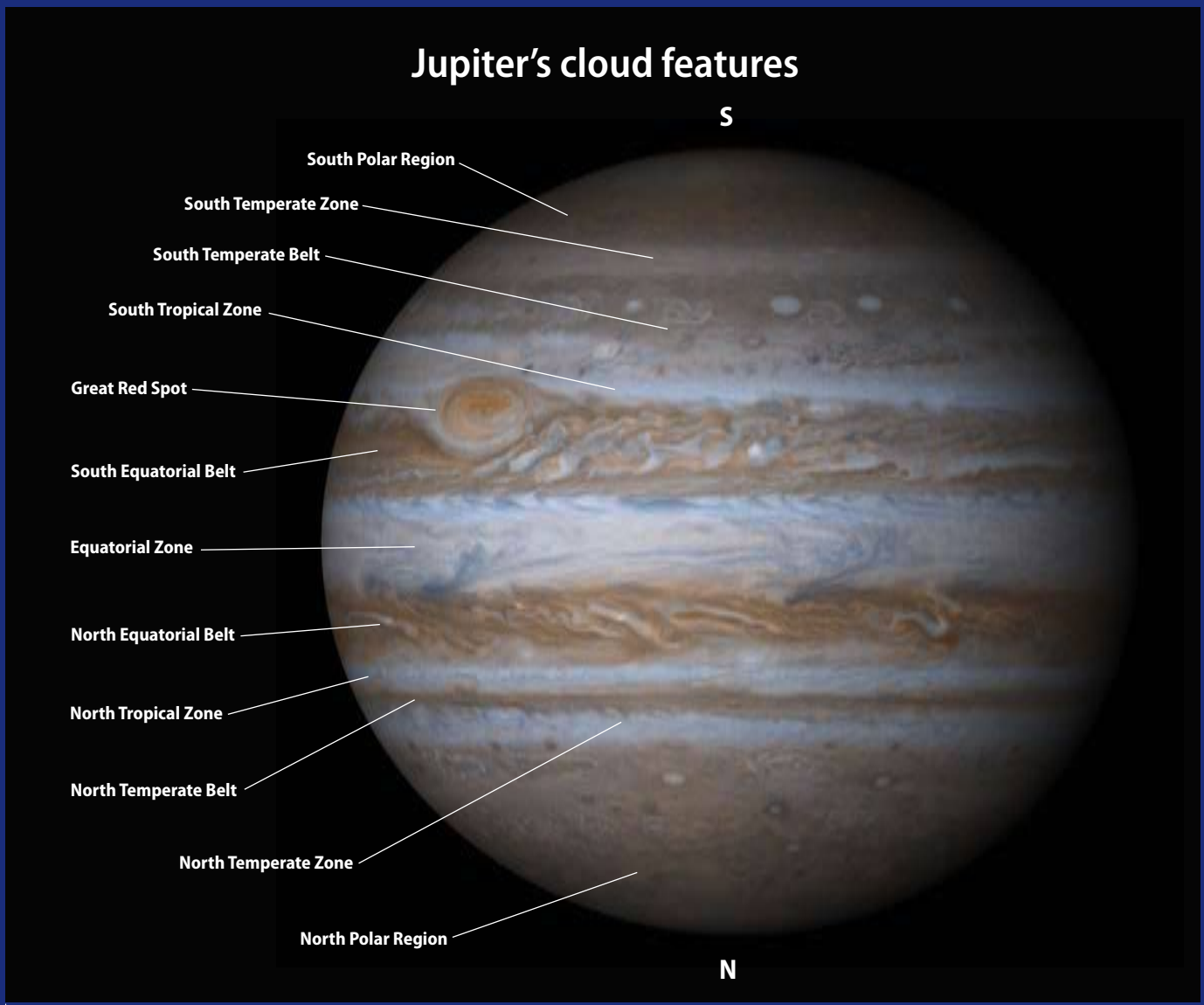
Far from being monotonous, watching Jupiter night after night can be a rewarding pursuit. In addition to the changing positions of its moons, the planet's rotation brings nearly all of its visible area into view in a single night around the time of opposition. Individual belts and zones may also become more or less prominent and even may disappear for extended periods.

Some observers contend Jupiter doesn't respond as well to high magnification as do Mars and Saturn because Jupiter has too much detail. High magnification tends to muddy the water, so to speak. In practice, this is more noticeable through low-quality telescopes. Through high-quality scopes, all that limits your view of detail is atmospheric steadiness.

Jupiter's clouds

Jupiter's atmosphere divides into cloud bands of various colors oriented parallel to the planet's equator. The lighter-colored bands are known as zones, and the darker colored ones are called belts. Within the zones and belts lie eddies, which may

Michael E. Bakich *is a senior editor of* Astronomy.



JUPITER ROTATES QUICKLY, so its cloud bands divide into belts (darker colors) and zones (lighter colors). Other features, such as the Great Red Spot, appear within the bands. Use this guide to help you identify atmospheric features. South is up.

produce temporary spots or streaks within or between Jupiter's cloud bands.

For more than a century, astronomers have been observing the Great Red Spot (GRS), and its discovery possibly stretches back to 1664. That year, English astronomer Robert Hooke (1635–1702) recorded a feature that was almost certainly the GRS.

The Great Red Spot is an anti-cyclonic (high-pressure) storm 22° south of Jupiter's equator. The closest analogy would be to a terrestrial hurricane. Because the GRS is anti-cyclonic in Jupiter's southern hemisphere, its rotation is counterclockwise, with a period of about 6 days.

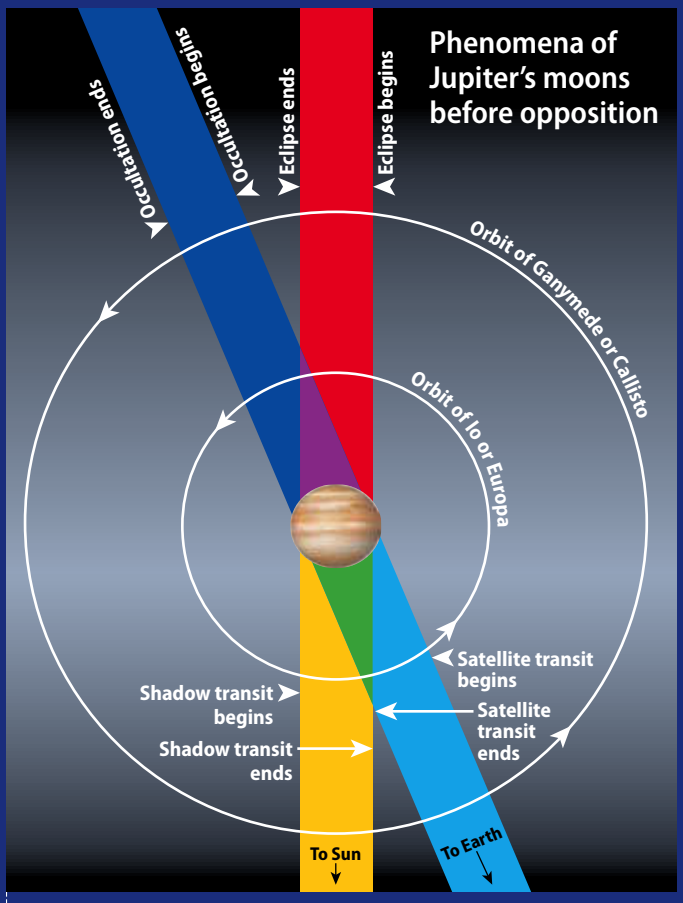
The Spot itself is enormous: It has a north-south width of 8,700 miles (14,000 km) and a variable east-west width of 15,000 to 25,000 miles (24,000 to 40,000 km). In recent years, though, it has been shrinking. The GRS's clouds appear to be about 5 miles (8 km) above neighboring cloud tops. We observe other features in Jupiter's atmosphere similar to the GRS, but none is as large. The GRS also drifts in longitude through the South Equatorial Belt. The GRS changes color (or fades, in the words of some amateurs) because clouds at higher levels and of different compositions condense above the spot.

Galileo's satellites

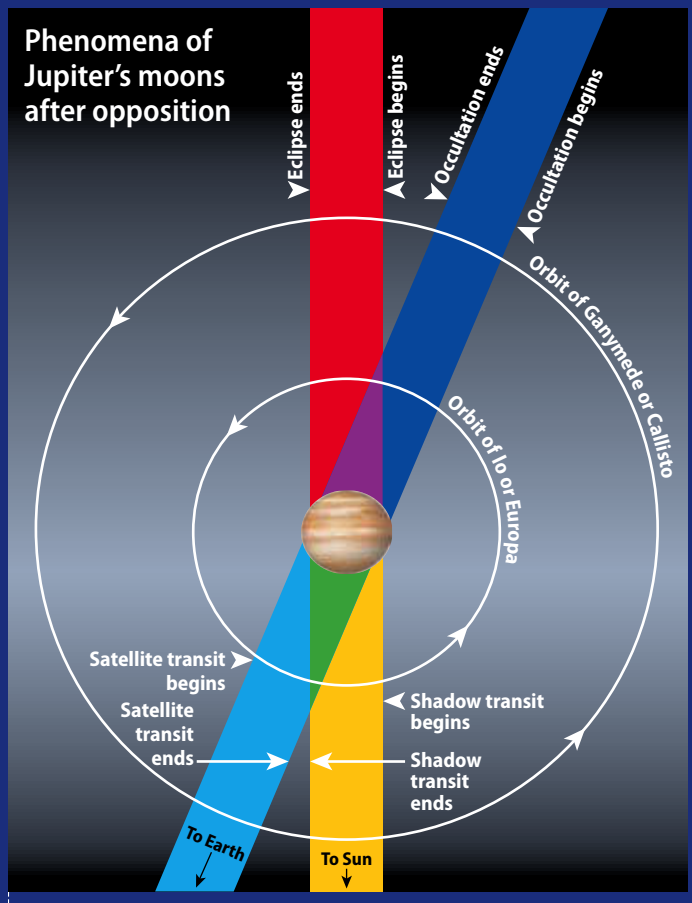
On January 7, 1610, Italian astronomer Galileo Galilei (1564–1642) looked through his telescope at Jupiter and saw three stars in a straight line, two on one side of Jupiter and one on the other. The next night, the stars were still there, but their positions had changed. On January 13, 1610, Galileo noticed a fourth star.

After observing these objects for weeks, Galileo concluded — and he could scarcely believe it — that the four "stars" were actually planets revolving around Jupiter in the same way the Moon circles Earth. Galileo's discovery of these four satellites — Io, Europa, Ganymede, and Callisto — made them the first observed solar system objects invisible to the naked eye.

Once you observe Jupiter's large moons enough to know which is which and how



BEFORE OPPOSITION, Jupiter's shadow lies east of the planet, and satellite events occur in the order shown.



AFTER OPPOSITION, Jupiter's shadow lies west of the planet, and the event sequence has changed.

JUPITER'S STATS

Equatorial diameter	88,650 miles (142,600 km)
Polar diameter	82,900 miles (133,400 km)
Volume	1,321 times Earth's
Orbital period	11 years, 315 days
Orbital velocity	28,060 mph (45,000 km/hr)
Rotational period	9 hours, 55.5 minutes
Synodic period	398 days, 21 hours
Distance from the Sun	5.2 astronomical units (AU)
	483,700,000 miles (778,300,000 km)
Angular size	
minimum	30.5"
maximum	50.1"
Brightness at opposition	
minimum	–2.0
maximum	–2.9

they move, it will be time to focus on each one more closely.

Through a 10-inch or larger telescope, and with good atmospheric conditions, you can observe details on the Galilean satellites. With high magnification (exceeding 350x), you'll resolve distinct disks, especially during transits, when the satellites' glare drops because Jupiter provides a lighter background than the dark sky. Try this on Ganymede. Look for light, shaded frost in its polar regions. Through larger telescopes, you can observe even the colors of Jupiter's Galilean satellites.

Satellite phenomena

Four events are possible involving Jupiter and its four large moons. A satellite eclipse occurs when the satellite moves through Jupiter's shadow.

A satellite occultation occurs when the satellite moves behind Jupiter. Galilean satellites always disappear into occultation at the west side of Jupiter and reappear at the planet's east side.

A satellite transit occurs when the moon moves in front of Jupiter. A transiting satellite always moves from east to west across Jupiter's face. The satellites themselves often appear as bright dots against Jupiter's dark belts. When a satellite lies in front of the brighter zones, however, it's hard to see unless you have followed it from the time it started to cross the planet's face.

A shadow transit occurs when a satellite's shadow moves across Jupiter's disk. You'll see the shadows as small black dots through any telescope. Transiting shadows also move from east to west across Jupiter.

Eclipse events are easier to observe than occultations because eclipses usually occur some distance from Jupiter's limb. Occultations take place at the brilliant planet's edge.

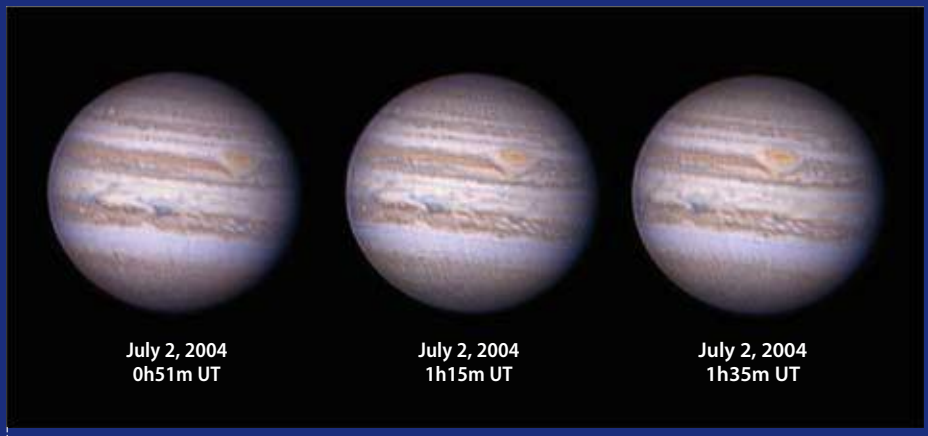
Prior to opposition, we see Jupiter's shadow to the west of the planet. Because of this, a satellite will undergo an eclipse before it is occulted. The satellite being eclipsed gradually fades as it enters Jupiter's shadow. Io and Europa each emerge from an eclipse after their occultation has

JOVIAN FUN FACTS

- Jupiter's **MAGNETOSPHERE** is the largest structure in the solar system. If it were visible from Earth, it would appear larger than the Full Moon.
- On a moonless night at a dark site, Jupiter can cast a visible **SHADOW.**
- At its equator, Jupiter rotates at 27,900 mph (45,000 km/hr), more than **27 TIMES** as fast as Earth.
- Astronomers named Jupiter's **EIGHT OUTER MOONS** (J6 to J13) based on how they orbit the giant planet. Those satellites with direct orbital motion have names ending in 'a' (Elara, Himalia, Leda, Lysithea). Those with retrograde orbits have names ending in 'e' (Ananke, Carme, Pasiphae, Sinope).
- On average, Jupiter travels 5' per day against the background stars. So, in a little over 6 days, **JUPITER MOVES** roughly the width of the Full Moon.
- The brightest satellite visible from Earth (not counting the Moon) is **GANYMEDE.** The solar system's largest moon shines at magnitude 4.4 when Jupiter lies at opposition.

DAMIAN PEACH

A PROJECTION MAP made from four images acquired between April 20 and April 30, 2005, shows Jupiter's cloud tops. South is up with the Great Red Spot centered.



DONALD C. PARKER

BECAUSE JUPITER spins once in less than 10 hours, you can see all of the planet's cloud features during one night. This sequence of three images shows only 44 minutes of Jupiter's rotation, but it's easy to see features moving from right to left.

started, so we can't observe their reappearance from eclipse (or their disappearance into occultation).

The two outer satellites, Ganymede and Callisto, usually lie far enough from Jupiter to be seen reappearing from an eclipse before an occultation. At opposition, Jupiter's shadow lies directly behind it. After opposition, occultations occur before eclipses, and — for Io and Europa only — the disappearance into occultation and the reappearance from eclipse are visible.

For transits and shadow transits occurring prior to jovian opposition, the satellite's shadow falls on the planet's disk before the transit begins. After opposition, the satellite begins its transit first, with the shadow following. The shadow remains on the planet even after the satellite has finished its transit.

In the 10 weeks before opposition, the Sun-Jupiter-Earth angle shrinks. As it gets smaller, the time between a satellite eclipse and its occultation decreases. The same holds true for the time between a shadow transit and a satellite transit. At opposition, these times coincide. After opposition, the Sun-Jupiter-Earth angle increases for about 3 months, and then it decreases again before Jupiter moves behind the Sun.

Jupiter through filters

All observers should use color filters when viewing Jupiter because filters bring out faint detail you won't see otherwise. If you've never used color filters, however, please note: Your views won't be colorful through them. Color filters produce monochromatic views that enhance the contrast between adjoining planetary features. At first, it takes a bit of getting used to, but once you do, you'll never observe Jupiter without them.

Green (#58) and blue (#38A) filters enhance the planet's dark reddish-brown belts. Blue also brings out the contrast within the bright zones and sharpens brighter cloud features. Yellow (#12) darkens bluish features, such as festoons, that appear from time to time within the equatorial region. Red (#23A or #25A) brightens and enhances white spots and ovals seen in the South Temperate Belts and Zone. Red filters also bring out blue features like festoons within Jupiter's Equatorial Zone as well as the northern and southern borders of the major belts.

For an object as bright and containing as many diverse features as Jupiter, amateur astronomers have tried some strange techniques, far beyond the range of standard color filters. *Astronomy* contributor Jeff Medkeff of Eagle River, Alaska, offers the following tip: "In narrowband filter land, light-pollution reduction filters can do dramatic things to Jupiter. The view becomes even more dramatic if you cut off the red end of the spectrum using a blue filter in conjunction with them."

Whether or not you use a filter, take this opportunity to study Jupiter. To northern observers, it may seem low in the sky, lying as it does in Libra, but it won't surpass this opposition altitude until September 21, 2010, when we'll find it in Pisces.

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Astroimagers captured their best views of Mars this past year. /// BY DONALD C. PARKER

Relive the Red Planet's big show

Although a planet, Mars turned out to

be one of the stars in 2005's sky. By its opposition November 7, amateur astronomers had contributed a record number of observations to organizations like the Association of Lunar and Planetary Observers (ALPO), the British Astronomical Association (BAA), and Japan's Oriental Astronomical Association (OAA). The International Marswatch web site also received some 4,400 CCD images and drawings from 83 observers scattered throughout 18 countries.

Despite the fact Mars was nearly 5" smaller at opposition in 2005 than in 2003, the quality of last year's images surpassed those of 2003. We can thank geometry: Mars appeared 32° higher in the sky for Northern Hemisphere imagers and, thus, was subject to less atmospheric turbulence.

Donald C. Parker *is the executive director of the Association of Lunar and Planetary Observers.*

Much of the improvement, however, reflects better imaging equipment and techniques, excellent image-processing software, and widespread use of color filters. Another factor is the propensity of Mars observers to share their techniques online at web sites like Geoff Gaherty's Mars Observers Group. Find it at groups.yahoo.com/group/marsobservers.

Better coverage

In the days of film astrophotography, amateurs couldn't obtain usable Mars images until the planet's apparent diameter exceeded 10". With the advent of digital imaging, exposures are now so short that an imager can beat distorting atmospheric seeing and produce excellent results when Mars subtends even 4". Thus, imagers can obtain useful data over a longer period of time.

In 2003, amateurs monitored Mars for nearly 1 martian year, a feat unequalled in ground-based observations. In 2005, quality observations began in March, although observers obtained some good data as early as November 2004, when the Red Planet subtended only 3.8".

Because Mars' day, or sol, is 39 minutes longer than ours, it's important that observers around the world monitor all longitudes of the planet. In 2005, amateur astronomers accomplished

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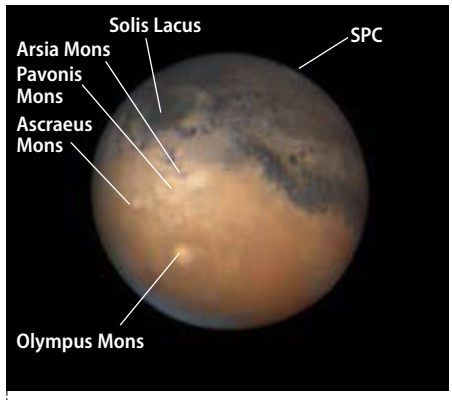
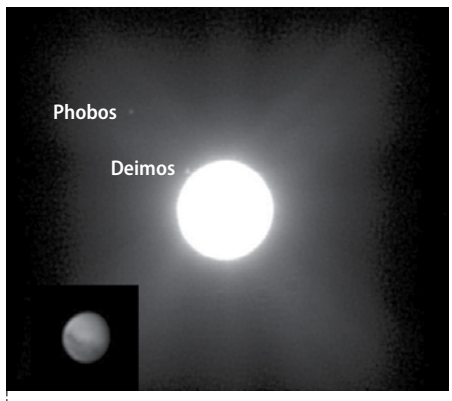


DAMIAN PEACH

ALTHOUGH MARS appeared 5" smaller in 2005 than at its best in 2003, photographers obtained excellent results this past year. The image above shows four giant shield volcanoes located in Mars' Tharsis region. Above them lies Solis Lacus, a dark albedo feature you can see through a 4-inch or larger telescope.



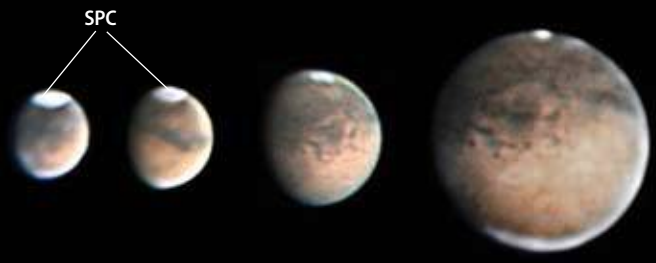
ADRIAN JONES

MARS HAS TWO MOONS, Phobos and Deimos, shown here October 3, 2005, at 1h19m UT. To record them, photographers must overexpose Mars. The inset, taken at the same time as the main image, shows the true size of the planet's disk.

Imagers capture martian details

November 22, 2004 | March 15, 2005 | April 14, 2005

MARS SHOWS DETAIL even when its disk subtends only 4". The sketch (left), completed November 22, 2004, reveals features when Mars measured only 3.9". The two digital images (March 15 [center] and April 14, 2005) present Mars' disk measuring 5.4" and 6.2", respectively. DAVID GRAY (LEFT SKETCH) AND ZAC PUJIC



May 26 (early spring) | June 17 (mid-spring) | August 4 (late spring) | October 13 (early summer)

MARS' SOUTH POLAR CAP (SPC) grows during fall and retreats in spring. In 2005, Mars' southern spring began in late March, so imagers captured the SPC sublimation. DONALD C. PARKER

July 30 | August 4

AS THE SOUTH POLAR CAP retreats, dark rifts appear, and the edge of the cap appears uneven. One of the most noticeable rifts is Rima Angusta, shown in these two images taken July 30 (left) and August 4, 2005. These dates fall within the martian late spring.

DAMIAN PEACH (LEFT IMAGE) AND LARRY OWENS

SPEAKING MARTIAN

ALBEDO FEATURE
A bright or dark permanent marking on Mars.

APPARITION
The period of time a planet is visible from when it first emerges from the Sun's glare until it disappears back into it.

ATMOSPHERIC SEEING
A measure of how steady the air is; in an image, the better the seeing, the more detail.

OPPOSITION
The point in an orbit when an outer planet lies opposite the Sun as seen from Earth.

PERIHELION
The point in a planet's orbit when it lies closest to the Sun.

RIFT
A groove or channel.

SUBLIMATION
The process by which a solid transforms directly into gas.

this continuously from August through November. During this time, they recorded many phenomena.

The polar caps

Mars' axis tilts 25.2°, comparable to Earth's 23.5°, so seasonal variations on the two worlds are similar. Of course, each of the four martian seasons is nearly twice as long as the corresponding Earth season. The axes of the two planets point in different directions. From Mars, the bright star Deneb (Alpha [α] Cygni) lies 10° from Mars' celestial north pole. This orientation means, at opposition, Mars is roughly one season ahead of Earth.

Opposition occurred November 7, during Earth's late autumn, so winter raged throughout Mars' northern hemisphere while summer reigned in the south. The most conspicuous indicators of martian seasons are the planet's polar ice caps, which wax and wane according to the season. During perihelic apparitions like the one in 2005, Mars' southern hemisphere is tilted earthward, and observers view the summer South Polar Cap (SPC). Mars' spring equinox occurred in late March (coincidentally like ours on Earth), so astronomers observed the SPC's sublimation — from the large, bright cap of early spring to summer's tiny remnant.

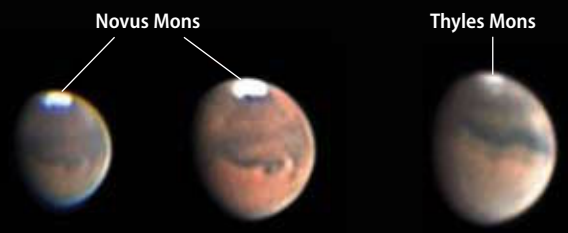
During the past 40 years, ALPO's Mars Section has worked with professional astronomers to measure the sizes of retreating martian polar caps. Results show variations in size and rate of regression from one apparition to the next, information that has contributed to our understanding of martian climatology.

During 2005, the many quality red- and infrared-filtered images provided an excellent database for the year's SPC regression. Preliminary results reveal that while the cap was initially larger than usual, its sublimation increased with unusual rapidity during mid-spring, when the regression more closely matched that of 2003.

As the SPC retreats, a number of rifts previously hidden by it appear. Also, patches of ice called outliers detach from the cap. The most famous of these is called Novus Mons, which separates in late southern spring, around the time of perihelion. The Mars dates when these rifts and outliers appear and disappear indicate martian antarctic climate changes.

In early July, observers reported the appearance of the North Polar Hood (NPH). Polar hoods are clouds of water-ice crystals and carbon dioxide that form over the polar regions during the martian autumn and winter. Astronomers once believed the winter polar cap grew beneath the hood and was uncovered when the hood dissipated with spring's arrival. In the

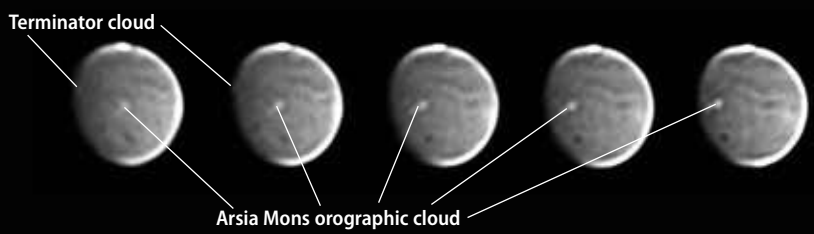
More martian details from imagers



AS THE POLAR CAP THAWS during martian spring, several bright, white projections detach from it. The most famous is Novus Mons, the "Mountains of Mitchel," discovered in 1845 by American astronomer Ormsby MacKnight Mitchel. 1) JIM PHILLIPS; 2 AND 3) ED GRAFTON

THE NORTH POLAR CAP forms during autumn and winter from the North Polar Hood (NPH), clouds of polar water-ice crystals and carbon dioxide. Astronomers once believed the cap grew beneath the hood to be uncovered when the hood dissipated. On October 25, 1992, the author took this infrared image revealing albedo features beneath the NPH, but showing no evidence of a cap. DONALD C. PARKER

OBSERVERS OFTEN NOTE morning and afternoon clouds along the martian limb. Such clouds form as the air warms because of sunrise, or cools near sunset. The author took this image October 18, 2005. DONALD C. PARKER



OROGRAPHIC CLOUDS are the most spectacular discrete clouds. They condense over highlands and volcanic peaks. This sequence, taken September 4, 2005, shows an orographic cloud over Arsia Mons. DONALD C. PARKER

ON OCTOBER 13, imagers captured a small dust cloud's evolution in northeast Chryse. After only 20 hours, the dust had expanded southward 1,100 miles (1,770 km). 1) CRISTINA AND FIORENZO MAZZOTTI; 2) SILVIA KOWOLLIK; 3 AND 4) CHRISTOPHE PELLIER

MARTIAN DUST CLOUDS can grow and shrink rapidly. On October 17, 2005, Houston astroimager Ed Grafton reported a tiny dust cloud over northern Chryse Planitia. By October 22, it formed a bright cloud extending from the western end of Coprates Chasma, arcing south and east into Argyre and covering roughly 1.9 million square miles (5 million square kilometers). By October 26, Solis

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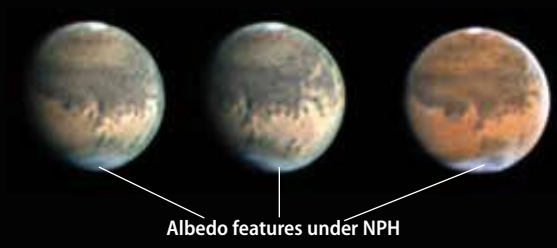
1960s, however, American astronomer Clyde Tombaugh theorized the cap actually forms from the hood.

In 1993, I imaged Mars through an infrared filter a few days before the northern vernal equinox and found albedo features lying beneath the NPH. I saw no evidence of a polar cap. In 2005, a number of observers imaged albedo features through the mid-winter NPH. Tombaugh's theory gained more proof when, in April, NASA's Mars Global Surveyor spacecraft imaged the SPC forming as its hood dissolved. The many excellent NPH images astrophotographers produced will help astronomers understand this complex feature and its relation to polar meteorology and dust storms.

Clouds

Although the martian atmosphere is tenuous, it displays active meteorology. As the polar caps sublimate in early spring, water vapor releases to form water-ice crystal clouds. In 2005, observers imaged these clouds near the SPC, along the morning limb (limb clouds) and over other regions (discrete clouds). The most spectacular discrete clouds are orographic ones, which condense over martian volcanoes and the Tharsis Bulge highlands.

During northern-hemisphere spring and summer, more discrete clouds appear; the number peaks after northern summer solstice. At that time, Tharsis orographic clouds form at local noon, brighten, and expand as afternoon progresses. By late

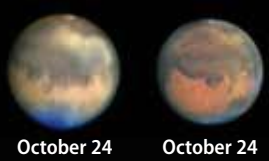


FEATURES VISIBLE in these 2005 images show the North Polar Cap (NPC) forms from the North Polar Hood (NPH). The late American astronomer Clyde Tombaugh, discoverer of Pluto, gets credit for advancing the correct theory of the NPC's formation. DONALD C. PARKER (LEFT, CENTER IMAGES) AND CHRISTOPHE PELLIER

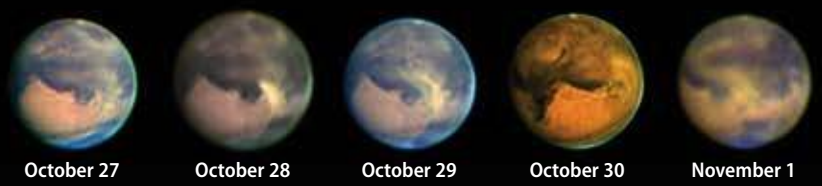
THE MARTIAN ATMOSPHERE is tenuous, but it displays active meteorology. As the polar caps sublimate, water vapor is released and forms ice-crystal clouds. The author imaged this cloud near the South Polar Cap October 13, 2005. DONALD C. PARKER

SEVERAL OROGRAPHIC clouds formed over Pavonis Mons and Mars' eastern Tharsis region. Astronomers sometimes call such features "domino clouds" because they resemble the dots on dominos.
1) DONALD C. PARKER; 2) ED LOMELI; 3) GERALD STELMACK

LATE MARTIAN SPRING saw the rapid retreat of the South Polar Cap. As it receded, small dust clouds appeared in high southern latitudes. The most conspicuous was a cloud that developed August 2, 2005. It extended fingers of dust northward for more than a week.
1) DAMIAN PEACH; 2) DONALD C. PARKER: 3) ED GRAFTON; 4) LARRY OWENS



Planum appeared clear of dust, while some dust was detected over Argyre through October 27. 1) DONALD C. PARKER; 2 AND 3) ED GRAFTON; 4) ROLANDO CHAVEZ; 5) ROLF MEIR; 6) JOEL WARREN; 7) ED GRAFTON



A LARGE DUST STORM appeared October 26, 2005. Amateur astronomer Joel Warren of Amarillo, Texas, reported a bright dust cloud extending from eastern Chryse Planitia into Aram Chaos. By October 30, it had extended into western Deucalionis Regio and had obscured most of Margaritifer Sinus and Meridiani Sinus. On November 1, the storm began to subside, and the region appeared mostly normal — if a bit lighter than usual — by November 3. 1) DAVE MOORE; 2) CLAY SHERROD; 3) DAVE MOORE; 4) JIM PHILLIPS; 5) TOMIO AKUTSU

afternoon, these clouds give Mars the appearance of a domino, or they may coalesce to form the letter W. In addition, spectacular orographics usually form over the Elysium shield volcanoes.

During southern spring and summer, discrete clouds tend to be less numerous, with orographic clouds forming in early spring. This early appearance may be due to water ice sublimating from the great Hellas and Argyre impact basins. In 2005, Mars' apparent size was too small for observers to detect this early phase of cloud formation, but the orographic clouds were spectacular in 2003 during the southern spring equinox.

A second stage of discrete cloud formation occurs near southern summer solstice. During this season, in late August 2005, Dutch astronomer Ralf Vandebergh reported an orographic cloud over the Tharsis volcano Arsia Mons. The cloud became prominent and persisted through opposition. In mid-October, additional orographic clouds were observed over Pavonis Mons and eastern Tharsis, forming "domino clouds."

Dust storms

Mars is dusty. Orbiters and landers image dust devils almost daily. On a larger scale, astronomers frequently see transient yellow or orange dust clouds obscuring part of the martian surface.

While massive planet-encircling storms are dramatic and firmly ingrained in Mars lore, they are rare. There have been only 10 such storms reported since 1877.

While smaller localized, or regional, storms can occur during any season, they are more prevalent during the southern hemisphere's spring and summer, when Mars is closer to the Sun. In 2005, observers were treated to several such events. Thanks to worldwide coverage and careful imaging techniques, observers captured many smaller and shorter-lived storms that would have gone unnoticed a decade ago.

All in all, 2005 turned out to be the best year yet for amateur astronomers imaging Mars. The image quality, image quantity, and coverage of the martian apparition were unparalleled. I can't wait to see what 2007 will bring.

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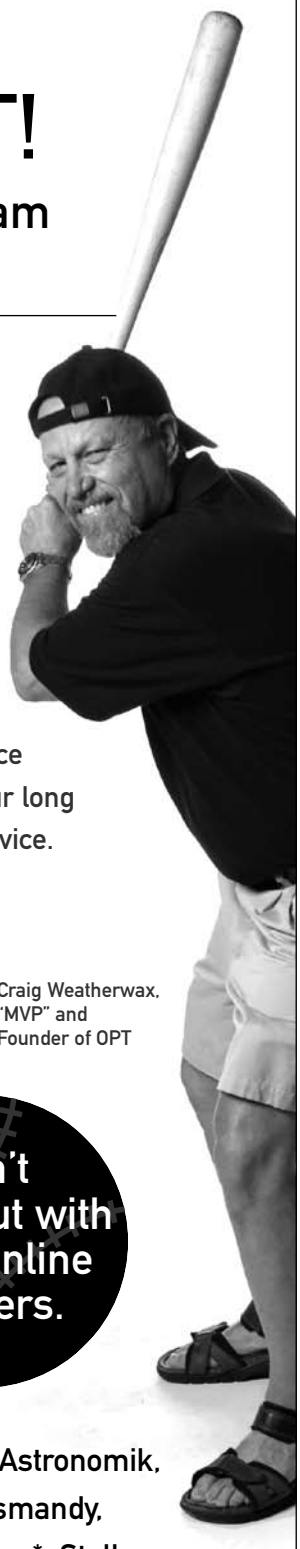

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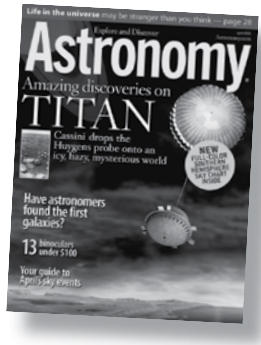

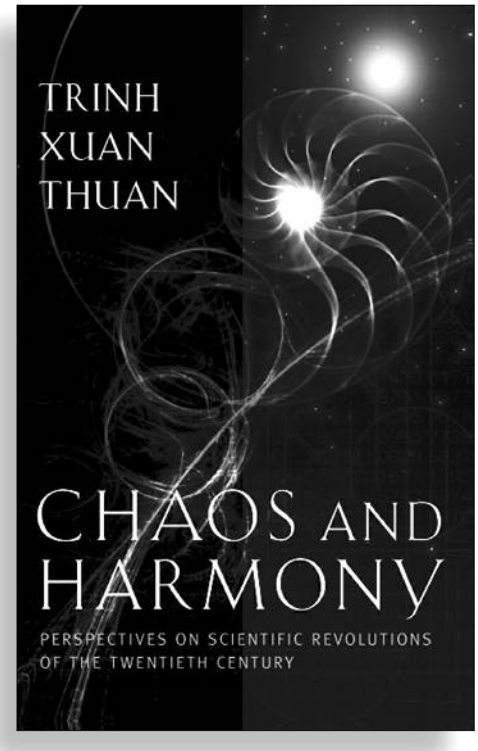

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Vixen's go-anywhere scope

Amateur astronomers have numerous telescope options, from simple designs to exotic optical configurations. Refractors, in particular, have gone through many incarnations. Recently, a number of different glass types and coatings have challenged the two-lens combination that makes up the primary objective of a standard achromatic refractor.

Enter the Vixen ED80Sf, a serious contender in the apochromatic refractor (APO) market. Vixen has established itself as one of the major competitors in this area. The ED80Sf is a 3.1-inch (80 millimeters) f/7.5 telescope with a 600mm focal length. At f/7.5, the ED80Sf falls into the medium-focal-length range.

From unpacking to setup

The ED80Sf package includes a 9x50 finder scope, a 2" eyepiece adapter, a Crayford focuser with tension/lock adjustment, a flip mirror assembly with T-threads and dual 1¼" eyepiece adapters, 100mm tube-mounting rings, and the standard Vixen dovetail mounting plate, which pairs with the optional Porta Mount's dovetail. A lightweight — but sturdy — aluminum tripod is optional.

FOR THIS REVIEW, the author used two Vixen LV Series eyepieces: the 5mm (120x) and the 22mm (27x). No eyepiece comes with the telescope.

The telescope, finder scope, flip mirror, and tube rings — along with an eyepiece or two — fit nicely in a custom padded, key-lockable travel case, which is included. This makes an easy-to-carry package. I already see myself taking this case as carry-on luggage for the next total solar eclipse, along with the Porta Mount and tripod — which are not too heavy or bulky and do not require counterweights — packed in checked luggage.

The telescope has high-quality machined components, tight-fitting construction, and an attractive overall finish. I had no trouble setting up the tripod, mount, and telescope, either at home or in the field prior to observing. The tripod adjusts to various heights. Its legs spread to their maximum distance when you deploy the attached leg spreader. A small but useful tray connects to the leg spreader by a small lock knob.

The alt-azimuth Porta Mount attaches to the tripod with Allen-head bolts. Vixen includes the two Allen wrenches you'll need under a protective rubber cover where the Porta Mount attaches to the tripod. Use one of the two wrenches to attach the Porta Mount to the tripod; the second adjusts the Porta Mount's motion tension. The location of the wrenches is convenient, and I like the protective rubber cover. With other scopes, it seems I'm always fumbling through a box looking (or feeling in the dark) for the proper size Allen wrench.

/// SPECIFICATIONS

VIXEN ED80Sf

Type: Apochromatic refractor
Lens diameter: 3.1 inches (80 millimeters)
Focal length: 600mm (f/7.5)
Tube length: 22.4 inches (570mm)
Tube weight: 7.5 pounds (3.4 kilograms)
Included: 9x50 finder scope, 2" eyepiece adapter, dual T-thread flip-mirror with dual 1¼" eyepiece adapters, Crayford focuser with tension/lock adjustment, rotatable dual-setscrew eyepiece adapter with locking collar, 100mm tube rings, dovetail tube plate, and custom aluminum case
Street price: $625
Porta Mount with aluminum tripod: $450

Contact information:
Vixen North America
32 Elkay Drive
Chester, NY 10918
[t] 845.469.8660
[w] www.vixenamerica.com

The manual altitude and azimuth slow-motion control knobs simply slide onto their respective worm shafts and stay on without tightening a thumb screw (which I have a habit of losing). I like this feature and found no issue in jarring loose the

Mike Reynolds *is an associate dean of mathematics and science at Florida Community College, executive director emeritus of the Chabot Space & Science Center, author of several astronomy books, and proud owner of more telescopes than his wife cares to count.*

THE VIXEN ED80Sf apochromatic refractor combines high-quality craftsmanship with an easy setup. ALL PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK

OPTIONAL ACCESSORIES include the Porta Mount and a lightweight aluminum tripod. Together, this setup weighs 12.1 pounds (5.5 kg). The dovetail groove in the Porta Mount accepts a matching plate attached to the telescope tube.

THE PORTA MOUNT attaches to the aluminum tripod (both optional accessories) with four Allen-head bolts. Both Allen wrenches you'll need for assembly reside in a magnetized, built-in storage bay under a protective rubber cover.

slow-motion control knobs — I tried. The telescope, with the tube rings and standard Vixen dovetail assembly, attaches easily to the Porta Mount. Once you fasten the telescope to the mount and tripod, check the balance along the tube's long axis. This was easy to do both in daylight and at night when I changed eyepieces.

The telescope is easy to use. This system doesn't boast go-to or clock-driven capabilities. Instead, the beauty of the Porta Mount lies in its simple alt-azimuth arrangement. Once you adjust the motion tension, the mount moves smoothly with just enough friction. The tripod included as part of the package seemed too light at first. Unexpected bumps at high magnification sent vibrations through the system, but they damped down in a few seconds.

The finder scope boasts 9x magnification and a 50mm diameter, which is quite sufficient for a finder. Its efficient dovetail-mounting system worked smoothly, and finder alignment was a breeze. Vixen employs a three-screw system. One of the three screws is spring-loaded, however, so it keeps continuous pressure on the finder scope. You need to adjust only the other two screws.

I appreciate a Crayford-style focuser because of its smooth motion. Vixen includes a 1¼" flip mirror with T-threads, which allows for straight or 90° viewing. The flip mirror moves smoothly and stops exactly where it should — a nice feature for those wishing to alternate between imaging and viewing. The flip-mirror system accepts only 1¼" eyepieces, so if you require a 2" diagonal, you'll need to purchase one separately.

SWITCHING FROM IMAGING to visual observing is a snap. The Vixen ED80Sf comes with a dual T-thread flip-mirror assembly with 1¼" eyepiece adapters. Vixen also includes a 2" eyepiece adapter.

To the sky

Once I set up the ED80Sf in the field, I was eager to see how it performs. I was not disappointed. For my review, two Vixen LV Series eyepieces accompanied this instrument: the 22mm (27x) and the 5mm (120x). I also used my own 1.7x Tele Vue Barlow lens. Theoretically, the maximum magnification for this telescope — going by the adage of 50x to 60x per inch of aperture — lies between 157x and 189x. In practice, however, I easily surpassed that limit: The 5mm plus 1.7x Barlow lens (204x) delivered high-quality images.

I made all of my observations with the Vixen ED80Sf under excellent sky conditions. I first tested the telescope on the First Quarter Moon. I checked for any excess color or internal reflections. The system showed none at any magnification or with any eyepiece/Barlow combination. The telescope performed well and produced sharp images with excellent contrast.

After the Moon, I observed Venus, Mars, and Saturn. The Association of Lunar and Planetary Observers recommends a 4-inch-diameter telescope as the minimum aperture observers should use for planet-viewing, but that didn't stop me from aiming the Vixen ED80Sf at these objects.

Although Venus lay relatively low on the horizon, the telescope delivered an acceptable image. When I turned the ED80Sf toward Mars and Saturn, I used the 5mm and Barlow lens combo. Planetary features were sharp with excellent contrast.

I next turned my attention to the stars, in particular Vega (Alpha [α] Lyrae), Sirius (Alpha Canis Majoris), and a number of double stars. I found the Vixen ED80Sf performed well at all magnifications and produced nice Airy disks with no false color. At high magnifications, the telescope also did a nice job splitting double stars with separations as small as 1.5". The background sky appeared black and even, which indicates minimal scattered light. Stars appeared as pinpoints with no distortion at any magnification.

Deep-sky objects were beautiful through the Vixen ED80Sf. Open clusters were stunning — I spent quite some time viewing the Pleiades (M45). Views of fainter open clusters proved equally rewarding. The high contrast (black background) coupled with tack-sharp images produced wonderful views at both 27x and 120x.

Globular clusters such as M2 and M15 also appeared stunning, as were a variety of nebulae. Because the winter sky loomed overhead, one of my primary targets was the Orion Nebula (M42). I resolved the four Trapezium stars easily once the constellation gained a little altitude.

With almost no effort, I found a street price for the Vixen ED80Sf package of $625. For this price, the ED80Sf is a good choice. And while you can buy more aperture for the same cost, this package — great optics, portability, ease of setup, a nice overall design, and outstanding views — ranks at the top of my list. A

THE ED80Sf boasts a 3.1-inch (80 millimeters) f/7.5 apochromatic triplet lens. The tube measures only 22.4 inches (570mm) long and weighs 7.5 pounds (3.4 kilograms).

EVOLUTION OF THE REFRACTOR TELESCOPE

Most achromatic refractors built from the 1950s through the 1980s had long focal lengths when compared to their reflector relatives. The primary reason involved excess color around images of bright objects. Many refractors had "issues" with chromatic aberration (where light of different colors arrives at different focal points).

This problem becomes less noticeable with long focal lengths because the lens doesn't have to bend the light rays as much. In a poor-quality refractor, one can see a blue or green Moon. Although it may seem cute to observe a "green-cheese Moon," most observers want true colors.

The types of small refractors — and the number sold — has grown significantly in recent years. Manufacturers present buyers with choices among high-quality achromats, refractors with fluorite lenses, semi-apochromats, and apochromats. The apochromat (APO) — a refractor employing three or more lens elements — ranks as the most expensive.

Not only is the correct lens-curvature combination essential, these components also must be made with special types of glass. And don't forget each optical surface has to be ground and polished to perfection. In a reflector, that means one surface: the mirror's front. In a three-element apochromat, the number of surfaces rises to six (the front and back of each lens).

In the past, high-quality refractors were not easily portable because of their long tubes, which required hefty mounts. But many new APOs combine shorter focal lengths, great color correction, and superb contrast. This means a portable instrument and high-quality views. — *M. R.*

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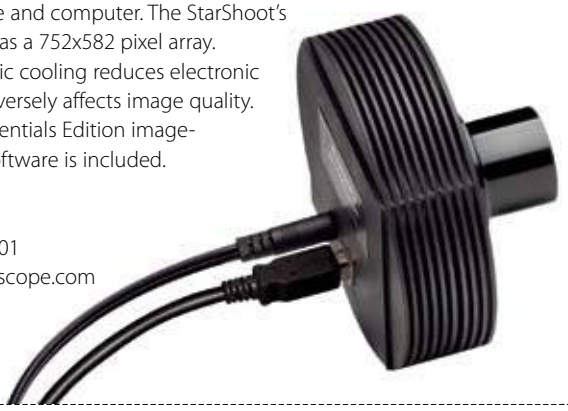

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Part of Meade's new LXD-75 line, this 8-inch Schmidt-Newtonian telescope features a German equatorial mount designed for high-precision observing and astrophotography. LXD-75s come with an all-metal field tripod that uses a spreader bar — with three 1¼" eyepiece holders — to lock each leg in place. The f/4 SN-8 has a focal length of 812mm and a resolving power of 0.56".

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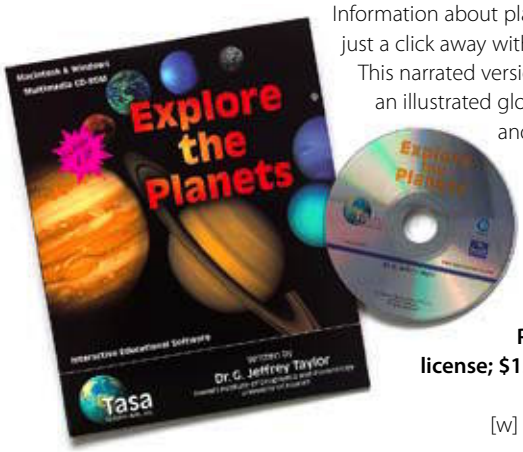

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NASA's Swift mission has helped astronomers solve the 35-year-old mystery of what causes short gamma-ray bursts.

Cassini unveils Saturn
Nearly 2 years into its extraordinary mission, NASA's Cassini spacecraft reveals the ringed planet's secrets.

Spiders from Mars
Dark, branching patterns on Mars' south pole link the planet's climate to its most prominent landforms.

Making waves
Astronomers see incredible detail with a technique called interferometry.

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JUNE 17–24, 2006

The Grand Canyon Star Party is held

at the canyon's north and south rims 80 miles (130 kilometers) northwest of Flagstaff, Arizona. The canyon's elevation, ranging from 7,000 to 8,000 feet (2,100 to 2,400 meters), and remote location ensure a clear, dark sky.

LIZ KRUESI

THE GRAND CANYON serves as a gorgeous backdrop for a star party.

Alternatives to observing include hiking, bicycling, and day trips to Lowell Observatory and Monument Valley.

The event is sponsored by the Tucson Amateur Astronomy Association. *Astronomy* Assistant Editor Jeremy McGovern will attend.

For more information, e-mail ketelsen@as.arizona.edu; web site, www.tucsonastronomy.org/gcsp.html.

JUNE 11–17; JUNE 20–27

Astronomy Camp for Teens

Mt. Lemmon Observatory, Coronado National Forest, Arizona. Part of the University of Arizona's astronomy-camp series, the first week is geared for teenagers who are beginning astronomers. The following session is for advanced observers. Activities include day and nighttime observing, lectures, and tours of the facilities. For more information, visit www.astronomycamp.org.

JUNE 16–17

Apollo Rendezvous

Dayton, Ohio. During the day, attendees will find exhibits, workshops, raffles, and vendors. The Apollo Rendezvous will present numerous lectures, including one by *Astronomy* Editor David J. Eicher. There will also be a cookout and observing at night. For more information, call Kevin Frederick at 937.236.4090; e-mail, kcrlfred@sbcglobal.net or mvas@mvas.org; web site, www.mvas.org.

JUNE 17

Web Cam Workshop

Kitt Peak National Observatory, Tohono O'Odham Reservation, Arizona. From cameras and accessories to imaging and processing techniques, learn all you need to know about producing great images with web cams from astrophotography expert Robert Reeves. For more information, call Robert Wilson at 520.318.8726;

e-mail, rwilson@noao.edu; web site, www.noao.edu/outreach/kpvc/imaging.html.

JUNE 21–24
Green Bank Star Quest
National Radio Astronomy Observatory, Green Bank, West Virginia. In addition to observing, the weekend includes imaging workshops, activities for children, and exclusive tours of the Green Bank Telescope, the world's largest radio telescope. SETI Senior Astronomer Seth Shostak is the keynote speaker this year. For more information, call 304.626.5012; web site, www.greenbankstarquest.org.

JUNE 21–26
Shingletown Star Party
Shingletown Airport, Shingletown, California. Each year, astronomy enthusiasts gather on the Shingletown Airport's runway for observing. Attendees also will find lectures, workshops, and vendors at this star party. For more information, visit www.shingletownstarparty.org.

JUNE 22–26
Cherry Springs Star Party
Cherry Springs State Park, near Coudersport, Pennsylvania. No other public site in this region has a darker sky than this star-party locale. Daytime activities will include workshops, contests, and lectures by comet-hunter Don Machholz, Al Nagler of Tele Vue, Inge Heyer from the Space Telescope Science Institute, and others. For more information, visit www.cherrysprings.org.

JUNE 22–25
Heart of America Star Party
Marais des Cygnes Wildlife Area, Butler, Missouri. This inaugural event will be held at the Astronomical Society of Kansas City's new dark-sky site. The location is primitive — you will need to supply your own power, food, and sleeping arrangements. For more information, visit www.askc.org/dssstarparty.pdf.

JUNE 22–25
Rocky Mountain Star Stare
Pike National Forest, near Colorado Springs, Colorado. The Colorado Springs Astronomical Society sponsors this event. Workshops, lectures, and contests will be held during the day. For more information, visit www.rmss.org.

JUNE 23–24
Craters of the Moon
Craters of the Moon, near Arco, Idaho. The high-elevation, remote location will provide a clear, dark sky for observers. For more information, contact Mike Hart at 208.528.7672 or Fritz Frauenholz at 208.588.3133; e-mail, mike@comdesign.com.

JUNE 23–25
Jersey Starquest
Hope Conference Center, Hope, New Jersey. This event will feature workshops, lectures, door prizes, and a swap meet. For more information, e-mail Don Monticello at dmonticello@hotmail.com; web site, www.princetonastronomy.org.

JUNE 23–25
North Dakota Star Party
Cross Ranch State Park, Center, North Dakota. Activities include lectures, observing, and a raffle. The state park, on the Lewis and Clark Trail, will celebrate the 1806 passage of the expedition through North Dakota. For more information, visit www.und.edu/org/nsas.

JUNE 29–JULY 3
Stargazing Manitoulin
Gordon's Park, Manitoulin Island, Ontario. Take advantage of the long Canadian national-holiday weekend. The site offers stargazing under the darkest skies in the region. In addition to observing, attendees will be treated to nature activities. For more information, visit www.gordonspark.com. A

CONTACT INFORMATION

Please submit club announcements 5 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

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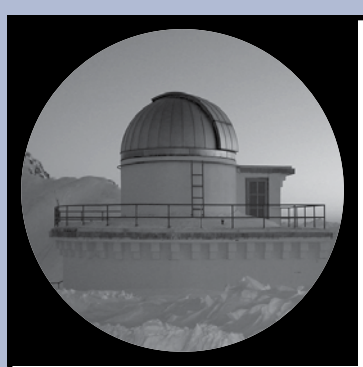

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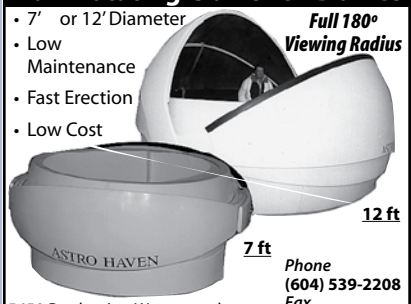

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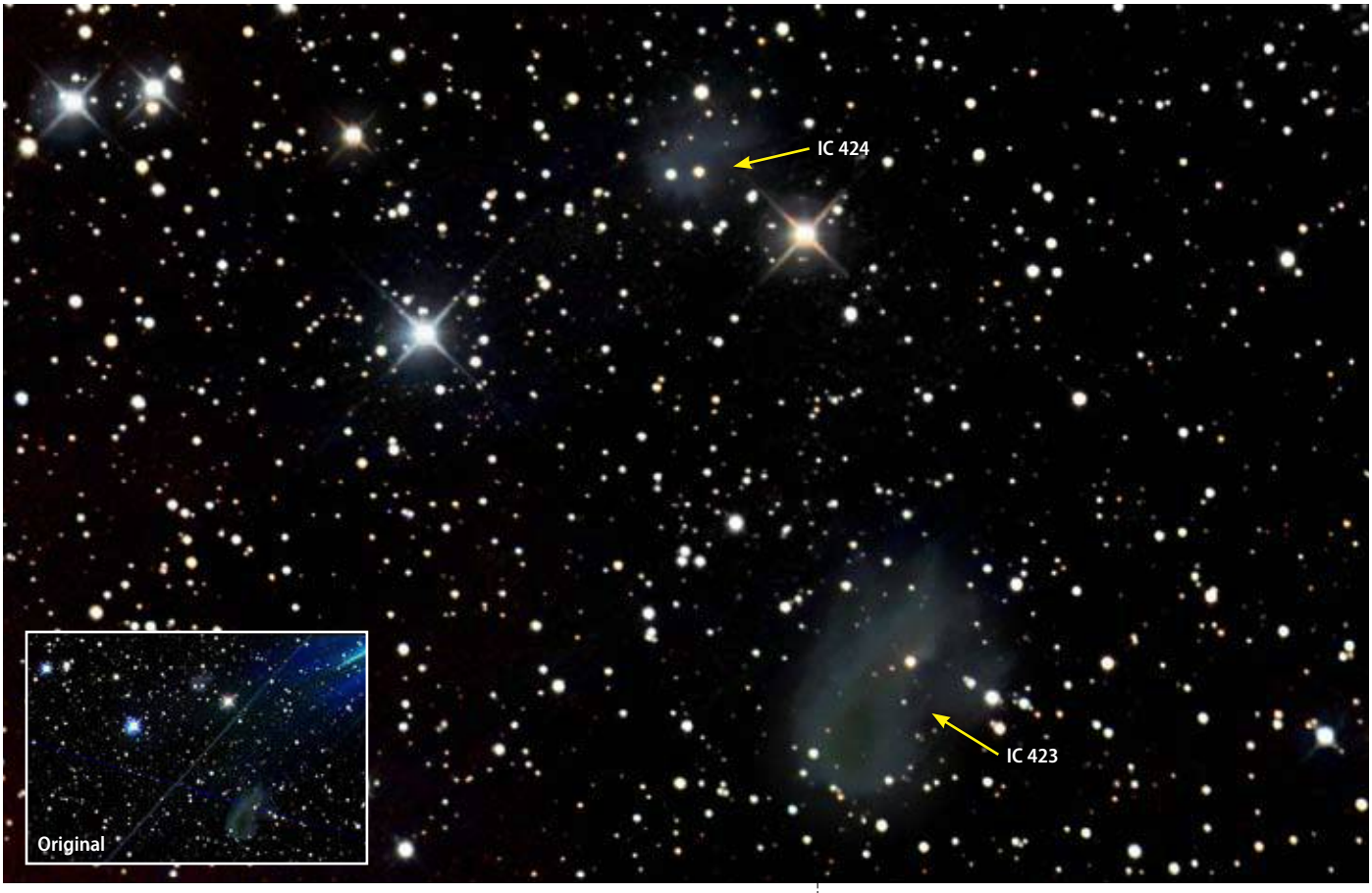

FAINT FUZZIES

"Other" Orion nebulae

Many wondrous objects fill Orion, from dark nebulae to brilliantly colored emission nebulae. The image above shows a pair of dim and strangely colored reflection nebulae lying about ½° southeast of Mintaka (Delta [δ] Orionis). This bright star (located just outside the field of view to the upper right) makes imaging the faint nebulae difficult because it creates glare inside the optical system. This is compounded by the huge number of Earth-orbiting satellites that fly through this part of the sky (the diagonal line in the original image).

IC 423 is the lower teardrop-shape nebula. It shows blue nebulosity with a core region colored brown and red because of obscuring dust. Above it lies IC 424, a slightly smaller reflection nebula.

▲ **REFLECTION NEBULAE IC 423 and IC 424** (12.5-inch homemade Newtonian reflector at f/5, SBIG 10-XME CCD camera, Astrodon filters, LRGB image with exposures of 60, 20, 20, and 20 minutes, respectively) /// **CHRIS SCHUR, PAYSON, ARIZONA**

NGC 7380 in Cepheus is a star cluster associated with nebulosity. In this region of space about 7,000 light-years away, stars form and light up the surrounding gas. (8-inch Celestron Schmidt-Cassegrain telescope at f/6.3, Starlight Xpress SXV-H9 camera, HαRGB image with exposures of 180, 20, 20, and 20 minutes, respectively) /// WOLFGANG PROMPER, GAENSERNDORF, AUSTRIA

THE BUBBLE NEBULA (NGC 7635) in Cepheus formed when an energetic wind from the magnitude 8.4 star SAO 20575 carved out a sphere in an interstellar gas cloud. (8-inch Celestron Schmidt-Cassegrain telescope at f/6.3, Starlight Xpress SXV-H9 camera, HαRGB image with exposures of 180, 20, 20, and 20 minutes, respectively) /// WOLFGANG PROMPER, GAENSERNDORF, AUSTRIA

Send your photos to: *ASTRONOMY* Reader gallery, P. O. Box 1612, Waukesha, WI 53187; e-mail to readergallery@astronomy.com.
Please include your full name, date and location of image, and complete photo data: telescope, camera, film, and exposure information.

OPEN CLUSTER M103 in Cassiopeia ranks as one of this constellation's underappreciated targets. Magnitude 7.4 M103 lies 8,500 light-years away, measures about 15 light-years across, and contains more than 150 stars. (4-inch Takahashi FS-102 apochromatic refractor at f/6, TOA-130 focal reducer, Starlight Xpress SXV-H9 CCD camera, Astronomiks Type II RGB filter set, LRGB image that combined six 4-minute L plus five 4-minute R, G, and B exposures; diffraction spikes created with two pieces of kite string placed perpendicularly in front of the telescope)
/// **STEVE CANNISTRA, NEEDHAM, MASSACHUSETTS**

ORION shines brightly over Gribloch House in central Scotland. Despite the brightly lit clouds, the imager took this picture near local midnight. (Canon EOS 300D digital SLR, 18–55mm zoom lens set at 18mm and f/5.6, tripod-mounted, 30-second exposure at ISO 1600) /// **NEIL ENGLISH, KIPPEN, SCOTLAND**

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Publishing Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Canada Publication Mail Agreement # 40010760.

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